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# NATIONAL RESEARCH COUNCIL

## AMERICAN GEOPHYSICAL UNION
## TRANSACTIONS OF 1939

## PART I
## REPORTS AND PAPERS
## REGIONAL MEETINGS
## (A) SOUTH PACIFIC AREA
## LOS ANGELES, CALIFORNIA, DECEMBER 16-17, 1938
## (B) NORTH CONTINENTAL DIVIDE AREA
## SPOKANE, WASHINGTON, DECEMBER 28, 1938

PUBLISHED BY THE NATIONAL RESEARCH COUNCIL
OF
THE NATIONAL ACADEMY OF SCIENCES
WASHINGTON, D. C.
JULY, 1939

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# PREFACE

The American Geophysical Union was established in 1919 as the American Committee of the International Union of Geodesy and Geophysics, and its Executive Committee is the Committee on Geophysics of the National Research Council. The objects of the Union are to promote the study of problems concerned with the figure and physics of the Earth, to initiate and coordinate researches which depend upon international and national cooperation, and to provide for their scientific discussion and publication. In the accomplishment of these objects, the Union is divided into sections following the plan of organization of the International Union of Geodesy and Geophysics. There are now seven sections, namely, (a) Geodesy, (b) Seismology, (c) Meteorology, (d) Terrestrial Magnetism and Electricity, (e) Oceanography, (f) Volcanology, and (g) Hydrology. A Section of Geophysical Chemistry was discontinued May 31, 1924, as the International Union had failed to provide such a Section; the Section of Hydrology was established November 15, 1930--matters pertaining to scientific hydrology referred to the American Geophysical Union had been previously looked after by special committees on Hydrology.

General assemblies of the Union and meetings of its seven sections for presentation and discussion of papers and symposia are held in Washington, D. C., each year. The first annual meetings were those of 1920. Following the formation of the Section of Hydrology, Regional Meetings have been held usually in joint sessions with other organizations having coordinated interests. For the purpose of such meetings, the Executive Committee of the Section of Hydrology designated selected Regional Areas and their territories, namely: North Continental Divide--Montana, Idaho, eastern Washington, Oregon, and Alberta (affiliated); South Continental Divide--Colorado, Wyoming, Utah, and New Mexico; North Pacific--western Washington, Oregon, Alaska, and British Columbia (affiliated); South Pacific--California, Nevada, Arizona, and Hawaii.

Thus far, Regional Meetings have been held as follows [references to publication of proceedings given refer to the "Transactions" of the American Geophysical Union, Part, and year]: South Pacific Area at Berkeley, California, June 20 to 21, 1934, jointly with Western Interstate Snow-Survey Conference, June 21, 1934 [Part II, 1934, pp. 522-611 and pp. 612-633]; South Pacific Area at Pasadena, California, January 31 to February 1, 1936, jointly with Western Interstate Snow-Survey Conference, January 31, 1936 [Part II, 1936, pp. 455-528 and 529-562]; South Continental Divide Area at Denver, Colorado, June 21 to 26, 1937, jointly with South Continental Divide Snow-Survey Conference, June 25-26, 1937 [Part II, 1937, pp. 509-600 and pp. 601-663, with addendum Part II, 1938, pp. 668-669], and with Society of American Foresters, June 22, 1937 [Journal of Forestry, v. 35, 1937, pp. 991-1055]; North Continental Divide Area at Spokane, Washington, December 28 to 29, 1937 [Part II, 1938, pp. 590-594]; South Pacific Area at Davis, California, January 8 to 9, 1938, jointly with Western Interstate Snow-Survey Conference, January 8, 1938 [Part II, 1938, pp. 595-667 and pp. 671-744].

The present volume of the "Transactions for 1939--Part I" contains the papers, symposia, and discussions at the Regional Meetings held for the South Pacific Area at Los Angeles, California, December 16 to 17, 1938, jointly with the Western Interstate Snow-Survey Conference, December 16, 1938, and for the North Continental Divide Area at Spokane, Washington, December 28, 1938, jointly with the Western Interstate Snow-Survey Conference, December 28, 1938.

The officers of the Section of Hydrology, and the officers and members of the Regional Committees responsible for the meetings at Los Angeles and at Spokane and of the Executive Committee of the Western Interstate Snow-Survey Conference, are as follows:

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J. E. Church, Vice-President
K. H. Beij, Secretary

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- James C. Marr
- O. W. Monson, Chairman of Spokane Program-Committee
- F. H. Paget
- R. L. Parshall
- R. A. Work

The costs of publication for the transactions of the Regional Meetings of the Section of Hydrology were provided by the American Geophysical Union. Those for the proceedings of the Snow-Survey Conferences were contributed by interested organizations and individuals, as acknowledged in the volumes, and by the American Geophysical Union. Assembly and preliminary editing of the manuscripts were made by the chairman of the meetings, by their chairmen of committees on program, and by Dr. J. E. Church. Final editing, preparing of master-copy, and publishing were done by Dr. J. A. Fleming and J. J. Capello, General Secretary and Assistant Secretary, respectively, of the American Geophysical Union. For the necessary redrawing of figures and photographic work for publication, we are indebted to W. C. Hendrix and P. G. Ledig.

Tribute must be paid to all who have taken part in the Regional Meetings and Snow-Survey Conferences as listed above and for 1938. Especially may be mentioned Dr. J. E. Church, whose stimulating enthusiasm and indefatigable interest and efforts have done so much to promote the development of snow-surveys and their value in the science of hydrology not only nationally but internationally.

J. A. Fleming, General Secretary,
American Geophysical Union

# AMERICAN GEOPHYSICAL UNION
# TRANSACTIONS OF 1939

## PART I
## REPORTS AND PAPERS
## JOINT REGIONAL MEETING
## SECTION OF HYDROLOGY
## AND
## WESTERN INTERSTATE SNOW-SURVEY CONFERENCE

### (A) SOUTH PACIFIC AREA
### LOS ANGELES, CALIFORNIA, DECEMBER 16-17, 1938

PUBLISHED BY THE NATIONAL RESEARCH COUNCIL
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## SOUTH PACIFIC REGIONAL MEETING, LOS ANGELES, CALIFORNIA, DECEMBER 16 AND 17, 1938

### Morning Session, December 16, 1938

The first session of the South Pacific Meeting, American Geophysical Union, Section of Hydrology, was called to order at 10:00 a.m., Friday, December 16, 1938, S. T. Harding acting as Temporary Chairman.

CHAIRMAN HARDING--I would like to explain that Professor O'Brien has been delayed. He was to preside at this morning's session. Being a member of the General Committee, I have been asked to substitute until he may come.

I have a letter from Mr. Sherman, who is President of the Section of Hydrology, stating that he will be unable to be here at this meeting. He sends us his best wishes for a successful session.

## THE HISTORY OF FLOODS IN SOUTHERN CALIFORNIA

Henry B. Lynch

This paper does not include the flood of March 2, 1938, and all comparisons are to be so construed.

The rivers of Los Angeles and San Bernardino counties are subject to destructive floods to a greater degree than are the streams in the remainder of the State. Torrential rains are almost characteristic of the drainage areas of the Los Angeles, San Gabriel, and Santa Ana rivers.

Since 1915 at least six storms have recorded rainfalls of ten inches or more in 24 hours in the mountains tributary to these streams. During this period 25 such reports have been received between Big Bear Dam and Haines Canyon, and three more from extensions of the line outside of the drainage areas of these streams. During the same period three such reports have been received from San Diego County, and one from the remainder of the State. These rainfalls are distributed by counties as indicated below. Each of these Southern California storms has produced floods.

| | Number | Percentage |
|---|---|---|
| Los Angeles. . . . . . . | 16 | 50.0 |
| San Bernardino . . . . . | 12 | 37.5 |
| San Diego. . . . . . . . | 3 | 9.4 |
| Remainder. . . . . . . . | 1 | 3.1 |
| | 32 | 100.0 |

In comparing present-day floods on the Los Angeles River with those of the past, account must be taken of the improved hydraulic properties of the River since work on it was started in 1887. Prior to that time the river-bed was a sandy stretch almost one-half mile wide, covered with willows and other growth. A profile made in 1875 shows the lowest point of the bed of the River to be only five feet below the level of the land west of the River. In addition to the small cross-section of the River, currents flowed slowly because of obstructions. The result was that large floods spread westerly to or beyond Alameda Street.

In 1887 the levees were constructed and the River confined between them. But even after the great flood of 1889, the bed of the River averaged 13 feet higher at Aliso Street than in 1931. As a result, the River will carry without overflow many times the volume of water which it carried in a natural state.

The seasonal rainfall-curve of California moves up and down in a manner not at present predictable. Some of the elements of this curve can be recognized, but as a whole it follows laws which are not understood.

The recurrence of floods follows roughly the ups and downs of the rainfall. A period of excess rainfall is always accompanied by frequent floods, while a period of deficient rainfall shows few or no floods. If an accumulated departure-curve is drawn using frequency of floods and droughts instead of indices of wetness, a curve results which follows in general the rainfall-curve.

In the 60 years prior to 1938 there are five floods in the Los Angeles River which can be classed as "capital" floods. Four of these occurred in the six years between 1884 and 1890. This period was far the wettest in the rainfall-history of Los Angeles. It shows well the relation between wet periods and floods. No capital floods have occurred in years having less than 150 per cent of normal rainfall

A comparison of floods is made difficult by the fact that each flood has individual characteristics. The flood of January 1916 was perhaps the greatest flood known in San Diego County, and was very heavy as far north as the San Gabriel River. In Los Angeles River it has been exceeded many times. The floods of 1891 and of 1927 were also much larger south of Los Angeles. Several of the floods in Southern California have occurred simultaneously with floods in Northern California, but many of the worst of them show no relationship. These floods have occurred as early as October 9 (1824) and as late as April 8 (1926). Most of them have occurred in December, January, February, and March.

As a result of the data from the Los Angeles River, it can be said that at Los Angeles a rainfall of four inches in 24 hours falling on dry ground will yield very severe street and local floods.

A rainfall of eight inches in ten days, of which the last day yields 2.5 or more inches, results in heavy floods. This statement is based on the assumption that mountain-rainfalls bear their normal relation to those of the valleys. When the mountains yield a greater rainfall than normal, heavy floods may occur in the valleys, even though the valley-rainfall is not as great as here given.

Spanish Period--From the time of the first occupancy of California by the white man, in 1769, floods in the rivers have occurred at intervals. The first flood noted was on the Los Angeles River and occurred late in December 1769 or in the early part of January 1770. This was noted by an expedition which marched from San Diego to San Francisco Bay and back. Father Crespi's diary says: "We crossed the plain in a southeasterly direction, arrived at the River and forded it, observing on its sands rubbish, fallen trees, and pools on either side, for a few days previously there had been a great flood which had caused it to leave its bed." Between 1770 and 1781 several floods are recorded. The floods of 1775-76 are described by several witnesses. The early part of the season was wet and floods were heavy.

From 1811 to 1821 floods and large crops were reported in each odd-numbered year. That of 1815 was an especially heavy one, and came on the west to the Los Angeles Plaza. This period was followed by a rainfall-shortage lasting 12 years. However, during that period there occurred in 1825 one of the heaviest of our floods. The season was a wet one over the entire province. Rain commenced early and at San Francisco there was a destructive flood on October 9, 1824. That is the earliest in the season of any flood of which I have record. In the following spring there were excessively heavy floods. In later years, all who testified before our local courts gave first place to this flood. Other heavy floods occurred in 1833, 1839-40, and 1841-42.

American Period--The period 1849-50 was a wet season, and heavy floods occurred on the Sacramento and its tributaries, on which had centered the gold rush. The Los Angeles River was also flooded, but accounts do not indicate that it was especially severe.

There was heavy rain in November 1859, followed by a severe flood in the Los Angeles River. This was repeated in December 1860.

In the winter of 1861-62 the entire West was visited by very heavy rains, which resulted in immense floods over all of the area. It is probable that the western rivers carried more water that year than in any other year since the coming of the white man. The Sacramento and San Joaquin rivers carried excessively large floods. Owens River raised its lake 12 feet. The Los Angeles River was heavily flooded, but the data seem to indicate that the flood was less severe in Southern California than in the north.

In the winter of 1867-68 there was another state-wide flood. It was not noteworthy in the north, but was almost as heavy in the south as the flood of 1861-62. The next floods of note in Southern California occurred in 1884. This winter was wet over most of the State and floods occurred everywhere. Around Los Angeles it was the wettest winter of which we have record. The Los Angeles River was high for most of the winter. Twice it gave very heavy floods. The peaks were not so high as in the flood of 1889, but they lasted longer and yielded more water. They rank immediately below that of 1889 in severity. In 1886 there was another very severe flood, not so large as those of 1884.

The flood of December 25, 1889, was the heaviest of the floods here listed since the local station of the Weather Bureau was opened in 1877. The season of 1889-90 was the next to the wettest season locally. The levees along the Los Angeles River were in place, but the bed was 13 feet higher than in 1931, and its carrying capacity was much less than now. All of the rivers of the south gave immense runoffs. The floods were state-wide.

In 1891 a moderate flood occurred in the Los Angeles River. To the south and east of Los Angeles the flood was much larger. There were moderate local floods in 1905 and 1906. The Sacramento River registered excessive floods in 1905 and in March 1907. Locally 1906-07 was wetter than average, but there were no floods of consequence.

The Los Angeles River showed a moderate flood in 1911 and in January 1914. This was followed in February by a heavy flood. This is the smallest flood in the Los Angeles Basin which has been designated as "capital." The season was wet over the entire State. In 1916 there was a flood of moderate dimensions in the Los Angeles River. To the south and east of Los Angeles this was perhaps heavier than any preceding flood. It did an immense amount of damage there.

There was a moderate flood in the Los Angeles River in 1927. On January 1, 1934, there was a local flood. In the Los Angeles River at Figueroa Street it was somewhat lighter than the flood of February 20, 1914. It was an exceedingly local flood which was extremely severe in some small streams. Several floods have been extremely severe in local streams and on streets without causing a great rise in the River. Three of these occurred in the season of 1889-90.

In February 1913, a Los Angeles rainfall of 5.12 inches in 24 hours caused heavy local floods. Just two days prior to the flood of February 20, 1914, 4.26 inches of rain fell at Los Angeles in 24 hours, of which 1.51 inches fell in one hour. There were excessive local and street floods, but not a great rise in the River. In April 1926 there was a somewhat similar flood.

Consulting Engineer,
108 W. 6th Street,
Los Angeles, California

## DISCUSSION

F. J. VEIHMEYER (University of California, Davis, California)--Going back over the history of floods, Mr. Lynch said that floods do not occur until after eight inches of rainfall.

H. B. LYNCH--I said major floods. Minor floods have occurred frequently but major floods do not occur until you have something of that magnitude.

## RAINFALL ON AND RUNOFF FROM SAN GABRIEL MOUNTAINS DURING FLOOD OF MARCH 1938

Maxwell F. Burke

On March 2, 1938, Southern California experienced a major flood, which equalled or exceeded any previous flood of record. Most recent figures made available through the courtesy of the United States Engineer Office at Los Angeles show that as a result of this flood 87 lives were lost and property was damaged to the extent of 79 million dollars. I would like to present to this meeting some of the rainfall- and runoff-data pertaining to this flood as it has been collected by the Los Angeles County Flood Control District.

In the cycle of rainfall which normally affects Los Angeles and vicinity, a season of rainfall above normal is generally followed by a season of rainfall below normal. To a betting man, the odds favoring this rule are about two and one-half to one, based on an examination of 65 years of record. Since the season of 1936-37 finished with about 150 per cent of normal rainfall, it was expected that the season of 1937-38 would fall below normal.

This expectation was fulfilled up to February 26, at which time the rainfall at Los Angeles was 10.67 inches, or 97 per cent of a normal season of 10.95 inches to that date. On February 27 a storm began which lasted until March 1 and brought about 4.4 inches to the city. During this period the maximum storm-total of 13.59 inches occurred at Hoegee's Camp, located in Santa Anita Canyon, which lies on the front face of the San Gabriel Mountains just east of Mount Wilson. The minimum values of between one and one and one-half inches occurred on the desert side of the San Gabriel Mountains, while on the coastal plain the rainfall was generally between three and four inches, with occasional records as high as five inches. From frequency-studies made on the Los Angeles Weather Bureau record for the 60 years ending in 1937, this two-day storm had a probable frequency of between five and ten years.

The maximum intensities for short times during this first storm were relatively small. From the Weather Bureau tabulation of intensities at Los Angeles, it appears that the intensities for periods of from five minutes to two hours were of probable frequencies of from two to four years.

Even though the rainfall-intensities for short-time periods were low, they were comparable with the intensities for the storm of March 2. As a consequence, the areas requiring very little rainfall to produce watershed-saturation, such as built-up urban areas, showed relatively high rates of flow. These valley-areas, served for the most part by storm-drains and improved collector-channels, respond in a very short time to rainfall, and as a consequence the peak-flows are governed largely by the short-time rainfall-intensities. Consequently, the peak-flows for urban-type drainage-areas in some instances approached to within 35 per cent of the March 2 peaks. These peaks during the first storm stood generally first or second in magnitude for the period of record to that time.

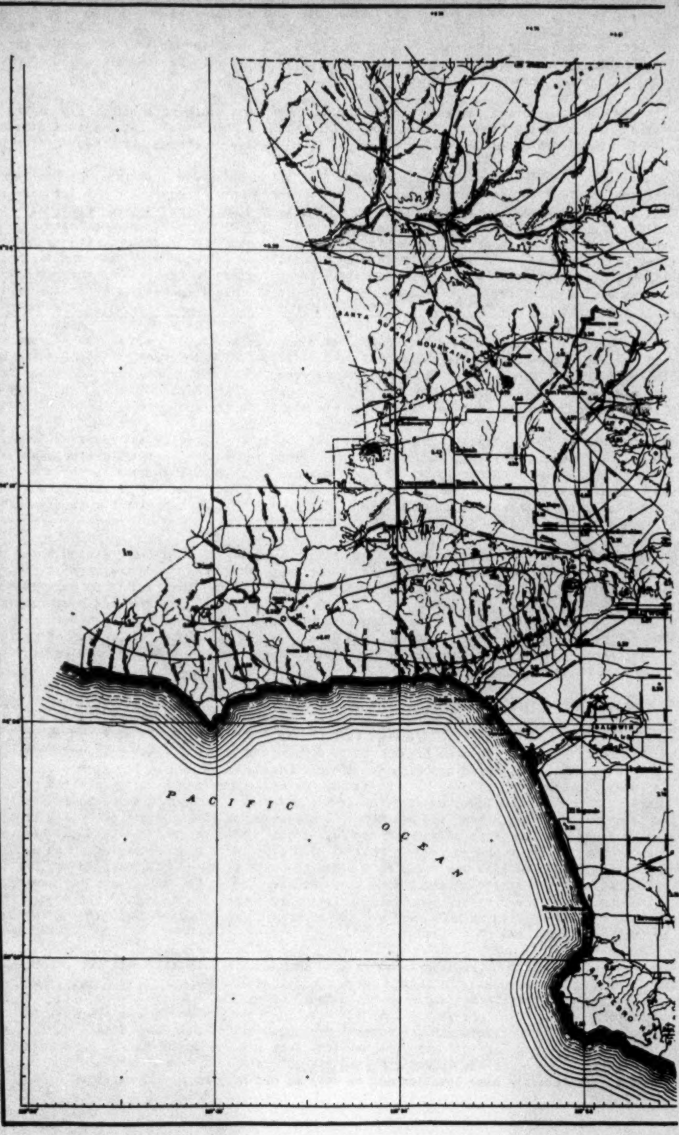
In the mountain-areas, on the other hand, where a large volume of rainfall is necessary to saturate the watershed before intensities affect runoff to a marked degree, the peak-flows were comparatively small. The peaks at the Flood-Control reservoirs ran from 50 to 120 second-feet per square mile and were generally from ten to 25 per cent of the March 2 peaks. They only gave a small glimpse of what was in store for the County within the next two days.

The volumes of runoff from the first storm were small, as judged by the measurements at the reservoirs. For average-rainfall amounts of from five to ten inches over the drainage-areas, runoff amounted to less than two inches as a maximum and only about one-third of an inch as a minimum. As a consequence, between five and eight inches of rain remained in the catchment-areas, producing near saturation-conditions and leaving the ground in a state favorable to immediate and high runoff from rainfall due on March 2.

In summarizing the storm of February 27 to March 1, it may be said that, although the rainfall-intensities were lower than had occurred in the past, the response on the part of the valley-streams originating in urban areas was more than generous, and the peak-flows were generally in first or second place in the record. In the mountains, the response was more niggardly and peak-flows were of a minor nature. The volumes of runoff in the mountains amounted to only about 15 to 20 per cent of the rainfall, leaving from five to eight inches of rain remaining on the catchment-areas. The first storm acted as a curtain-raiser, and set the stage for an all-star performance to be featured on March 2.

The second storm started throughout the county at about ten o'clock on the night of March 1 and continued in the mountains without any prolonged interruption until around six o'clock in the morning of March 3. In the valley-areas rain ceased for several hours at about seven o'clock in the evening of March 2. A tabulation of 24-hour rainfall-values for the period from 5 p.m. March 1 to 5 p.m. March 2, which approximates the maximum 24 hours during the storm, resulted in the isohyetal map (see Fig. 1). As will be noted, the minimum rainfall shown on the map is about two inches in the desert-region. On the area draining southerly to the ocean, the rainfall increased from around three inches near San Pedro to a maximum of 15.28 inches at Opid's Camp in the headwaters of the West Fork of the San Gabriel River. The high rainfall-belt extended along the ridge of the frontal range of the San Gabriel Mountains, with a secondary offshoot extending northeasterly from San Gabriel Dam No. 2 to include the high peaks of Mt. Islip, Mount Hawkins, and North Baldy. Another high rainfall-zone shows at the edge of the map around Mt. San Antonio. From these high zones the rainfall decreased continuously toward the desert. In general, it may be said that the rainfall in this 24-hour period amounted to about 50 per cent of the total rainfall in the period February 27 to March 4.

Previous to this storm, frequency-studies had been made on all daily rainfall-records in the County of 15 years or more duration. From these studies it was possible to determine the probable frequency of the 24-hour rainfall during the March 2 storm. Frequencies thus obtained for 33 stations varied from once in 325 years to once in three years, with an average of once in 66 years. This may be considered as the general frequency of the 24-hour rainfall during the storm. However, the range of indicated frequencies, from 3 years to 325 years, also indicates the difficulties which beset the hydrologist who has to explain why this storm may be classed as an economic maximum for some location and as only an ordinary storm for others.


SANTA MONICA MOUNTAINS
BALDWIN HILLS
PACIFIC OCEAN
SAN PEDRO H

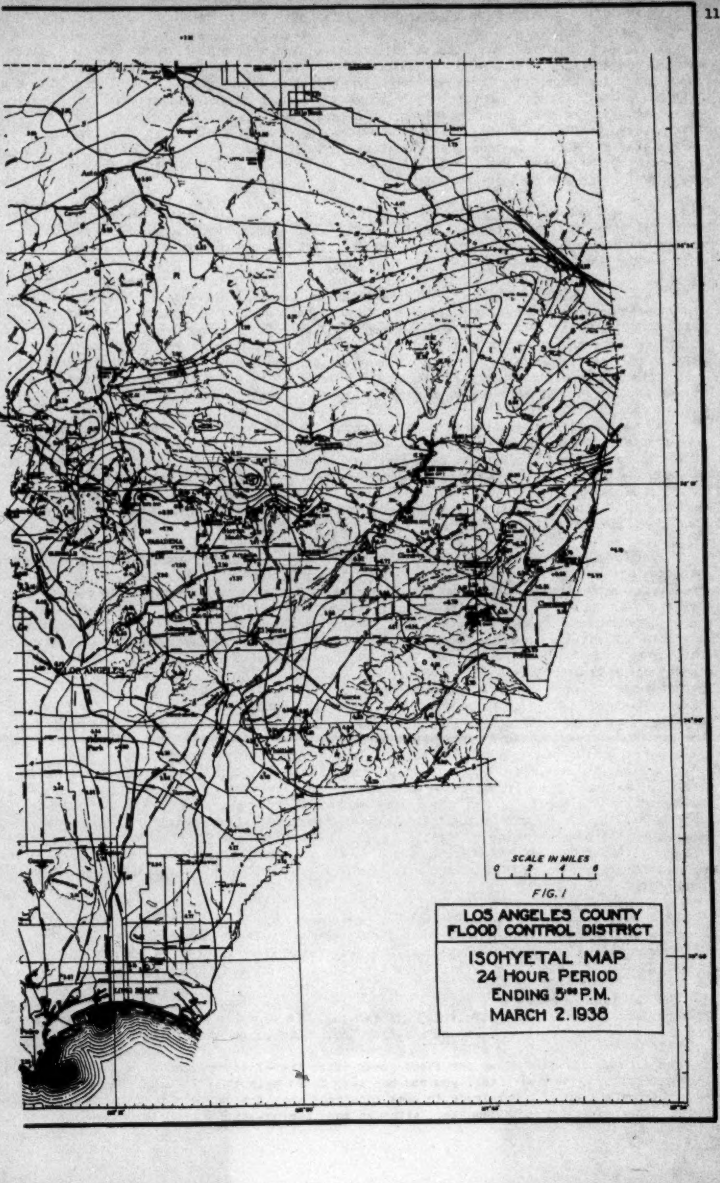

PASADENA
LOS ANGELES
LONG BEACH
SCALE IN MILES
0
2
4
6

FIG. 1

LOS ANGELES COUNTY
FLOOD CONTROL DISTRICT

ISOHYETAL MAP
24 HOUR PERIOD
ENDING 5:00 P.M.
MARCH 2. 1938

A further comparison was made on the relative magnitude of this storm and past storms of record. During the record-period of 1877 to 1938, eight storms may be selected as being of flood-producing magnitude. These occurred in 1884, 1889, 1914, 1916, 1921, 1926, 1927, and New Year's 1933-34. Without troubling you with rainfall-amounts, a few statistics may prove interesting. Of the nine stations selected, four representing valley- or foothill-conditions and five located in the mountains, six stations show the maximum day's rainfall occurring during the 1938 storm, while two stations show the storm of 1921 and one shows the New Year's, 1934, storm as recording the maximum day's rainfall. No mountain-records are available for the 1884 storm and only one for the 1889 storm.

For the total storm-rainfall, four of the stations show the recent storm as the largest, while four show the 1921 storm as the largest. The remaining station shows the New Year's storm as having the largest total. Again, no mountain-records are available for the 1884 storm and only one for the 1889 storm.

The storm rainfall-values for each station were computed in terms of the March values and these percentage-values averaged for each storm. The figures thus obtained indicate that for the maximum day's rainfall the March 2 storm was the greatest, followed by the New Year's storm at 80 per cent and the 1921 storm at 78 per cent. For the total storm-rainfall, the recent storm was the greatest followed by the 1921 storm at 95 per cent and then by the 1914 storm at 79 per cent. The storms of 1884 and 1889 apparently show relatively low percentage-values, but this may be explained by the absence of any mountain rainfall-records.

Two automatic rain-gages have been maintained in the County for a period long enough to give some frequency-data. These two stations are the United States Weather Bureau at Los Angeles, with a 38-year record and Opid's Camp, previously mentioned, with a 12-year record. Previous to the storm these records had been analyzed by frequency-methods for durations of 5, 10, 15, and 30 minutes, and 1, 2, 5, and 24 hours. The probable values for a 50-year frequency were then combined into the familiar intensity-duration curve (see Fig. 2). In this figure are shown also the maximum values for these same periods selected from the record for March 2.

Figure 3 shows the same results arranged in a little different manner. The probable frequencies have been plotted against the various time-periods selected. These curves show that the March 2 storm was characterized by exceptionally infrequent intensities for time-periods of five hours or more, while the intensities for time-periods of less than an hour are of more common occurrence. It also appears that the storm was relatively more severe in the mountains than it was in the valley, since the time-period intensities at Opid's Camp all show a greater probable interval between recurrences than the same time-periods at Los Angeles. For instance, the 30-minute intensity at Opid's Camp has a probable frequency of once in 12 years, while the 30-minute intensity at Los Angeles has a probable frequency of once in five years. In other words, the maximum 30-minute intensity recorded during the March 2 storm probably would occur more than twice as often at Los Angeles as it would at Opid's Camp. The same analysis holds for the other time-periods and results in roughly the same ratios.

A further investigation was made of the maximum hour's rainfall recorded at automatic rain-gage stations by comparing these values with the Flood Control District's iso-intensity map used in allocating capital flood rainfall-intensities. From this comparison, approximate frequencies were obtained. It is significant that 90 per cent of the stations thus investigated showed that the maximum hour's rainfall had a probable frequency of once in five years or oftener, that for five per cent of the stations the probable frequency fell between five and ten years, and that for five per cent the probable frequency was between ten and 25 years. No frequency thus found exceeded 25 years.

As a summary of the rainfall-situation, the total storm about equalled the rainfall during the storm of December 1921 and exceeded all other storms during known flood-periods. The maximum day's rainfall exceeded previous days' maxima during flood-periods by about 20 per cent. As an average, the maximum day's rainfall had a probable frequency of 65 years.

The rainfall-intensities for time-periods less than two hours were smaller than would be expected for a storm of this magnitude. In general, the probable frequency of intensities varied from once a year for a five-minute duration to once in 60 years for a five-hour duration.

The determination of flows for flood-peaks after the flood has passed is beset with numerous difficulties, as anyone will tell you who has been faced with the problem. The runoff from the present storm was of such magnitude in some locations that the ordinary means of gaging and recording gage-heights were inadequate. Although many gaging-stations had been installed and were

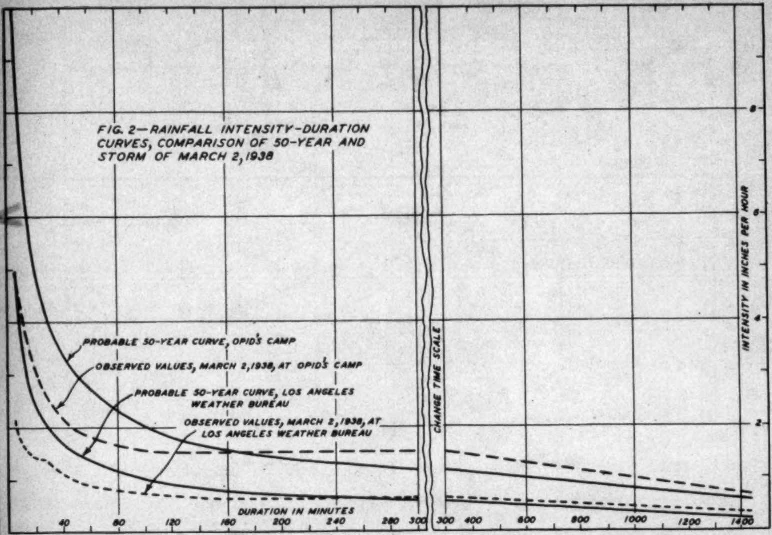


FIG. 2—RAINFALL INTENSITY-DURATION CURVES, COMPARISON OF 50-YEAR AND STORM OF MARCH 2, 1938

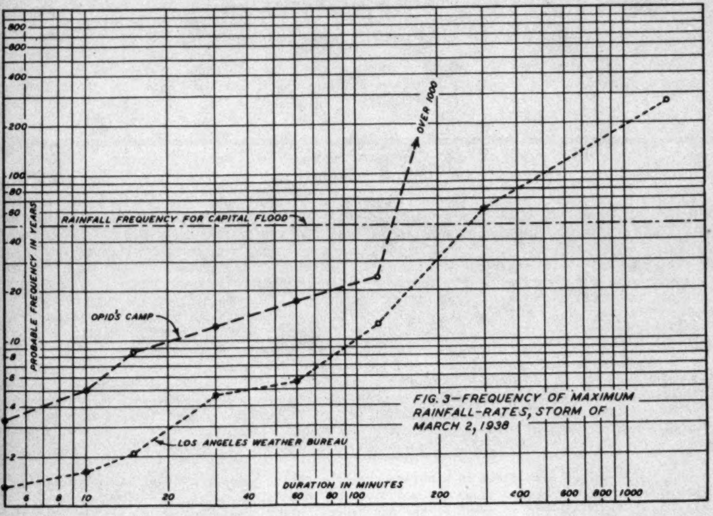


FIG. 3—FREQUENCY OF MAXIMUM RAINFALL-RATES, STORM OF MARCH 2, 1938

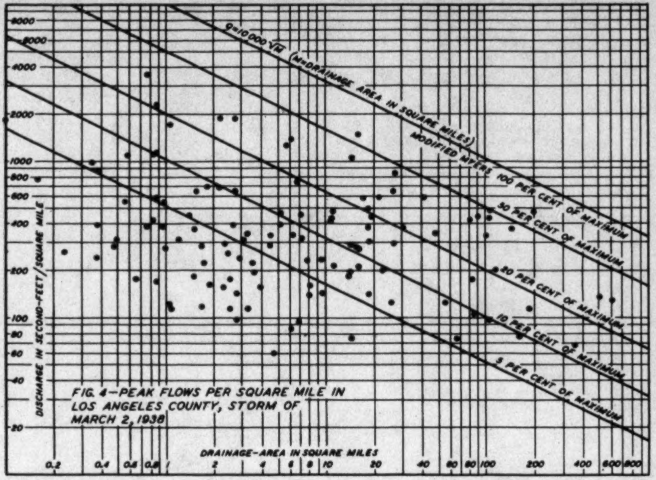


FIG. 4—PEAK FLOWS PER SQUARE MILE IN LOS ANGELES COUNTY, STORM OF MARCH 2, 1938

in operation before the flood, as the water rose several of the hydrographers realized that the installations were insecure for a flood of the magnitude then apparent, and so removed the recorders and the record up to that time to save what they could. Several instances were reported where the recorder was on the point of being washed away when it was removed. Furthermore, it was physically impossible for hydrographers to tend to all the stations assigned to them because bridges were washed out, streets were flooded, and travel was all but impossible.

One of the brighter spots in this picture, from the point of view of the hydrologist endeavoring to set the magnitude of the flood, is the fact that the Flood-Control District had built 15 reservoirs in the mountainous area. Attendants were on duty at these dams throughout the flood, making periodic checks on reservoir-stages, outflow, and valve-settings. These data enable one to compute the inflow-hydrograph using the outflow-rates and the storage-rates in the reservoir. It is believed that the data thus obtained form the most reliable estimate of the runoff from the storm.

Other methods of estimating flood-peaks include channel-rating curves, estimates of flow over weirs and falls, estimates based on cross-sections of flood-channels taken after the passage of the flood, and field-estimates made by hydrographers at the time of the flood. This arrangement is in the general order of reliability. All these methods, with the exception of the reservoir-storage method, rely basically on knowledge of velocity and cross-sectional area. While the velocity may be ascertained within reasonable limits, the area is generally highly uncertain due to changes in the bottom by scour or deposition. In the high velocities encountered in streams in Los Angeles County, soundings to determine the bottom are practically impossible for high stages. Debris, both floating and bouncing or dragging along the bottom, adds its particular difficulties. All this dissertation on the difficulties encountered is not in the nature of an alibi, but is intended to point out that estimates of this type partake largely of the judgment and experience of the estimator, and two men with the same set of data will normally arrive at two different answers. The figures which I intend to submit are those contained in the report of the Los Angeles County Flood-Control District on this flood. Other reports made and in process may, and probably will, show different peak-values. A reviewer is free to choose whatever values appeal to him.

Figure 4 shows the peak-flows on a per-square-mile basis, as computed by the Flood-Control District. A number of computed flows are not shown on this Figure due to the uncertainty of tributary drainage-area. As an example, the San Gabriel River splits into two channels below Foothill Boulevard, and the percentage of flow going down each channel is unknown. Thus, it is impossible to give a fair figure for the area to the main river-channels below this split. This restriction applies to the Rio Hondo, the San Gabriel below the split, and the Los Angeles River below the junction with the Rio Hondo.

Some of the points shown in Figure 4 may bear explanation. For example, the two points showing the highest rates of runoff per square mile are for Pasadena Glen and Rubio Canyon. These peaks were estimated from cross-sections made after the flood and were taken at definite control-sections. While some allowance was made for debris undoubtedly contained in the flow, no estimate of the bulking was possible, and the peak-flows as shown may be considered essentially clear-water flows.

One point of considerable interest in this flood is the volumes of runoff produced. While peaks are important for purposes of channel-design, volumes of runoff are particularly important when reservoir-operation is considered. The hydrographs at the District's reservoirs give a good indication of the volumes of flow produced.

As mentioned previously, the volumes of runoff produced by the first portion of the storm were of minor character. However, the volumes of runoff produced by the storm of March 2 were decidedly not of minor character. In general, the maximum 24-hour runoff-period began between 7 and 10 a.m. March 2. The maximum 24-hour runoff has been compared with the 24-hour rainfall and percentage of runoff-figures derived. Listing the reservoirs by size of drainage-area, it is found that the percentage of runoff varies in the same manner, the largest drainage-areas producing the highest percentages of runoff. For the area tributary to San Gabriel Dam No. 1, with a drainage-area of 202 square miles, the 24-hour runoff was 64 per cent of the day's rainfall. For Live Oak Dam, with 2.30 square miles of drainage-area, the value dropped down to 33 per cent. Intermediate drainage-areas show percentage-values between these figures decreasing with decreasing areas. These percentages exceed by several times previous record values and are from 100 to 150 per cent of values computed for the capital flood.

To show what these runoff-quantities mean in terms of reservoir-storage and consequently in ability to regulate the flows, the maximum 24-hour volumes of runoff were computed in terms of the total capacity of the reservoirs to spillway lips. Excluding Puddingstone Diversion Dam, which is used for diversion only, Puddingstone Reservoir, which is a terminal reservoir, and the Sierra Madre Dam, which is a debris-retarding reservoir, the following ratios are obtained. The 24-hour runoff-volumes varied from 70 to 400 per cent of the capacities of the reservoirs to receive them. The high figure goes to Big Tujunga Dam No. 1, where in 24 hours enough water entered the reservoir to fill it to the spillway-lip four times. Incidentally, the flood-peak and volume at this point were approximately three times any peak or similar volume of record.

Santa Anita Dam stands next in line with a maximum 24-hour runoff-volume of 3.4 times the capacity of the reservoir. As a result of this volume, water overtopped the dam for a period of more than an hour, without, however, doing any damage to the structure. At only two of the reservoirs was the 24-hour volume less than the capacity of the reservoir.

And how do the figures for the 1938 flood compare with past figures and estimates? Some indication has been given by the comparison of present and past peaks on the Big Tujunga, where the present figures are three times as large as past records. On the Los Angeles River the 1938 flood materially exceeded any previous flood of record. It was from two to four times as large as the New Year's flood of 1934 and about twice as big as any previously recorded flood. On the Arroyo Seco, the present flood and the 1914 flood show the same peak-flow for Devil's Gate Dam. On the San Gabriel River, the present flood exceeded all previous floods of record by a considerable margin when the regulating effect of San Gabriel Dam No. 1 and Morris Reservoir is considered. The maximum estimates at the Forks for the 1884 and 1914 flood were exceeded by the present flood. On the Rio Hondo, a comparison is hard to make due to the split of San Gabriel water, but the present flood-figures are as large or larger than previous figures with the possible exception of the 1914 flood.

For the minor stream-channels, about the only general conclusion which can be drawn is that where the streams originate in the mountainous area the present flood is the greatest of record, and, for streams originating on the valley-floor, some previous records have been greater.

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## DISCUSSION

[This discussion followed Dr. Krick's talk which is not presented in these Transactions.]

M. P. O'BRIEN (University of California, Berkeley, California)--Engineers have always used, as a probable diagnosis for the future, figures based on the past. After listening to Dr. Krick's paper, I wonder what our air-mass analyst has to say on this possibility and I wonder if he has any data on this subject?

IRVING P. KRICK (California Institute of Technology, Pasadena, California)--I think, owing to the results that I have heard here, it is more economical to design on the basis of the figures that have been used in the past because it is only once in a hundred years that we are going to have a catastrophe and will have to build everything over again. In the present direction that we are moving, I do not see any way that will enable us to meet these economic conditions satisfactorily.

## THE FUNCTIONS OF DEBRIS-DAMS AND THE LOSS OF RESERVOIR-CAPACITY THROUGH SILTING

E. C. Kenyon, Jr.

The purpose of this paper is to discuss briefly the functioning of debris-control structures in this region and the loss of storage-capacity due to the accumulation of debris in local flood-control reservoirs. In considering these subjects it is, I believe, essential that we have some conception of the why and the wherefore of the debris-problem as faced here in Los Angeles County. In less arid localities there is little relationship between control of floods and control of debris. Here in Southern California, in some instances, when we control debris-movement we go a long way in controlling floods.

To understand the processes by which debris accumulates at certain places along a mountain-front in a semiarid region it is important to know the essentials of the physiographic history of that region. The term "physiographic history" refers to the chain of events which has produced the present topography. In Southern California that history, according to geologists, began in Pleistocene time. From a human point of view the Pleistocene period seems very remote because it antedates the race. From a geological point of view, however, it was but yesterday. Hence, the subsequent history is very short and comparatively simple.

During the Pleistocene period the crust of the Earth in this locality suffered severe deformation and was broken into a number of large fault-blocks. One of these blocks was thrust upward several thousand feet to form the San Gabriel Mountains. At the same time, the adjacent blocks to the south dropped to form the structural basins of the San Fernando Valley, the Main San Gabriel Valley, Pomona Valley, and numerous others. As a result of this deformation, a mountain- and valley-topography was established in Los Angeles County, but in appearance it was far different from that which now exists.

On the whole, that early topography was represented by a huge mass of granitic rocks towering above a number of irregular-shaped and tilted granitic basins. It must be remembered, of course, that this topography was not produced by a single great cataclysmic upheaval. On the contrary, the differential movement of the fault-blocks was a slow and gradual process. Moreover, the mountain-mass was dissected as it was elevated and the structural basins were filled with mountain-debris as they were depressed. Hence, there was a gradual transition from an early topography which we can scarcely conceive to the present topography which is so familiar to us.

Toward the close of the Pleistocene period the locality of deformation shifted southward away from the mountain-front and the subsequent history has been comparatively simple. It has consisted of two coincident processes, continued degradation of the mountains, and continued aggradation of the basins.

Today we see the steep, rugged San Gabriel Mountains rising abruptly on the north to a height of 8,000 to 10,000 feet above sea-level overlooking a gently-sloping valley-floor of vast alluvial deposits, in some locations over 2,000 feet in depth.

A number of fault-zones occur within this mountain-range. The most important of these is the San Gabriel, some 45 miles in length and extending in an easterly-westerly direction. This fault-zone has largely determined the location of the east and west forks of the San Gabriel River and sections of the Arroyo Seco and Big Tujunga streams. Many of the smaller canyons and their tributaries have been influenced by the location of innumerable minor fault-zones. Approximately 1,200 square miles of area have been fractured by these zones. Within this area there now exists a huge mass of disintegrating rocks very susceptible to weathering.

Weathering of rocks is accomplished by various agencies working together. The most important of these are water, wind, large diurnal temperature-variations, growing plants, gravity, and oxygen in the air. The first five of these agencies exert physical action upon the rock-masses and cause them to disintegrate. Oxygen produces a chemical change causing the rocks to alter their mineral forms or decompose. The disintegration and alteration of rock-masses produce the debris which is eventually carried out of the mountains by the streams.

The accumulation of debris in the bottoms of canyons is the first stage in its transportation toward the valleys. The principal methods of such accumulations are by gravity, by the erosive action of water, or by a combination of gravity and water. If rocks are badly fractured or sheared, large blocks may be dislodged by weathering agencies, thence gradually sliding down the slopes, or they may drop directly into the bottom of the canyon.

If rock-masses are resistant and not broken by large joint cracks or shear planes, the debris may consist entirely of "fines," that is, disintegrated and altered particles weathered from the exposed rock-faces. A large proportion of these fines reach the bottom of the canyons through the erosive action of water. This type of debris-movement is called "sheet-erosion."

In some places weathering may penetrate deeply into a rock-mass, and then after the weathered material becomes saturated with water the entire mass may move down the slope in a landslide. This type of debris-movement is of frequent occurrence on our steep canyon-slopes, especially when the sustaining toe of the slope is undercut by the scouring effect of stream-flow in the channel.

The second and final stage in debris-movement is its transportation out of the canyons by running water, and in that movement the velocity of the water is the controlling factor. The small, high-gradient canyons along the mountain-front carry flows only after local storms. Such flows are generally loaded with debris; hence, they do not scour channels of any material size and the greater part of their debris-loads is dropped immediately below the mouths of the canyons and then spread out to form "fanglomerates." Fanglomerate accumulations differ from true alluvial cone-deposits in that they consist of unassorted materials varying from large sub-angular rock-masses to sands and clay. The rounded boulders and fair sorting found along the larger stream courses are conspicuously scarce.

In most of the mountainous areas in Southern California nature has, over a long period of time, developed a covering of brush. This brush-cover, consisting of low, dense masses of shrubs, is, in reality, a low-forest type of growth. The mantle of litter which is produced by this brush-cover is a natural erosion-control agent. Its effectiveness in controlling erosion during the flashy storms experienced in this region has been proven conclusively both by experimentation and by field-observation.

In an experiment conducted at the Devil's Canyon plots on the San Bernardino National Forest in 1927-28, it was found that the first year after the plots were burned over the denuded plots produced 18.1 times as much material as those brush-covered.

Similarly, field-observations indicate the tremendous increase in debris-movement during a storm from a denuded watershed. Following the New Year's 1934 flood which caused so much damage in the Montrose-La Crescenta area, I inspected several of the canyons in which the flood-flows originated. Of particular interest were the conditions observed in Haines Canyon. This watershed was only partially burned over in the fire which swept the mountains in that vicinity in November 1933. Near the upper end of that canyon, the watershed divides into two branches, each about 0.2 of a square mile in area. The one extending to the northeast was completely burned over, while the one to the northwest escaped the fire. A total of 12 inches of rain was recorded during the New Year's flood at the Flood-Control District's automatic rain-gage located near the confluence of these two canyons. Rainfall-conditions were probably similar on both the burned and unburned water-sheds, considering the relatively small area involved. Inspection showed that runoff- and debris-movements starting high up in the headwaters of the burned-over canyon developed into what appeared to have been a flood-flow of a thousand second-feet or more by the time it swept into the main channel of Haines Canyon. In marked contrast the peak-flow from the unburned canyon was estimated to have been something less than 100 second-feet with no indication of any appreciable debris-movement having occurred within the watershed.

Los Angeles County, like "Topsy," has just "growed." With the rapid influx of people in the last three decades natural watercourses have been encroached upon throughout the County. At best what were poorly-defined and inadequate stream-beds have today, in some cases, become all but obliterated. People have built homes below hundreds of small canyons either unaware or indifferent to the fact that they were in the natural paths of debris-movement.

In order to prevent extreme loss of life and property below these smaller watersheds, should a fire denude them, it has been necessary to devise some means of debris-control before the flood-flows reach the built-up sections. Such control has been developed by the construction of either debris-dams or debris-basins.

Debris-dams are structures of either concrete or earth-fill, the storage-capacities of which are above normal stream-bed. They are in most cases constructed upstream from the mouths of the canyons. They require, of course, suitable foundation- and abutment-conditions for safety and good reservoir-sites to provide adequate capacity. Only a few of the many small canyons in the County provide these requirements, thereby limiting the number of possible installations. Five dams of this type have so far been constructed in the Los Angeles County.

Because of the lack of suitable dam-sites, another type of debris-control structure, known as a debris-basin, has been developed in this vicinity. The first one was constructed in Haines Canyon in 1928 and proved so satisfactory during the New Year's flood that 15 more have since been constructed.

Storage-capacity of a debris-basin is obtained primarily by excavating a basin 20 to 40 feet deep, although additional capacity is obtained by the construction of a spillway-structure from five to ten feet in height above stream-bed. An inlet-structure consisting of a rectangular chute into the basin is necessary to prevent channel-cutting upstream. Spillway- and inlet-structures are constructed of either wood or concrete.

Debris-basins have in most cases been constructed just in, or below, the mouths of canyons to be protected. Since they are relatively low structures, they can readily be cleaned out after storms, thereby restoring their original capacity at a low cost per cubic yard compared with the more expensive costs experienced in desilting debris-dam reservoirs.

The principal function of these structures is to provide storage-capacity for the debris in flood-flows. By removing the debris-load, the runoff from denuded areas can be reduced to relatively small flows, thus reducing the necessary capacity of flood-control channels built below them.

The extent to which runoff from a denuded area may become loaded with debris was brought out by a small, flashy storm which occurred October 18, 1936. Pickens Canyon is one of the watersheds above Montrose which was burned over in the 1933 fire previously mentioned. In 1936 the Flood-Control District completed the construction of a debris-basin located approximately one mile below the mouth of the canyon. The channel above the debris-basin is unimproved, passing through typical alluvial deposits. Surveys of capacity in the basin before and after the storm provided accurate figures on debris and water-volumes which were impounded.

The rain began falling at 12:20 p.m. according to the record obtained from the District's automatic rain-gage located near the mouth of the canyon. Between that time and 3:00 p.m. only 0.25 inch had fallen, insufficient to cause runoff. No rain fell between 3:00 and 3:36 p.m.

Between 3:36 and 3:54 p.m. the rain fell at a rate of 0.93 inch per hour. During the next nine minutes the rate increased to an average of 2.67 inches per hour, dropping off to an intensity of 0.90 inch per hour between 4:03 and 4:11 p.m. Only 0.01 inch fell during the last 19 minutes of the storm.

During the 35 minutes between 3:36 and 4:11 p.m. a total of 0.80 inch fell on the 1178 acres of watershed above the basin at an average rate of 1.37 inches per hour. Measurement of high-water marks indicated that a peak-flow of approximately 1000 cfs entered the basin. Near-by residents stated that the flow into the basin occurred in one big flood-wave with very little runoff occurring either before or after. All of the flood-discharge was impounded in the basin, reaching a depth of approximately 20 feet.

The total volume of debris and water amounted to 25,011 cubic yards. A survey after the water had drained off showed a debris-deposit of 22,062 cubic yards. The volume of impounded water, exclusive of that in the voids of the debris, amounted to 2,949 cubic yards. Considering the debris-deposit as wet solids, the ratio of wet solids to free water amounted to 7.46 to 1. Expressed in percentages this gives an average volume for the total flow of 88.2 per cent wet solids and 11.8 per cent free water.

Flood-discharges, as they leave the canyon mouths, generally have a much wider cross-sectional area than the channels constructed to carry off the flows. Debris-basins thus have an important function as a transition-structure between confined and unconfined flow.

In many small storms, debris-basins impound considerable volumes of water as well as debris. In this capacity they function somewhat as spreading-grounds since most of them are constructed over fairly deep alluvial deposits. At Pickens and Hall-Beckley Debris-Basins, the District made some measurements on percolation-rates soon after the basins were completed. Rates observed then were probably the maximum as no silting-up had as yet taken place.

The percolation-rate at Pickens Debris-Basin during a period of ten days with a head of water varying from 17 to 8 feet amounted to 0.69 cfs per wetted acre at the start of the period and gradually declined to a rate of 0.29 cfs per wetted acre. At Hall-Beckley Debris-Basin during the same period the head dropped from 15 to 10 feet and the percolation-rates declined from 0.41 to 0.13 cfs per wetted acre. In comparison, average rates of percolation in District spreading-grounds over a like period of time will range from four to two cfs per wetted acre.

The large amounts of fines in suspension in the water in the debris-basins soon seal up the pores in the sands and gravels; hence, extremely low rates of percolation result. The effectiveness of a debris-basin and concrete channel-system in controlling floods was given a good test during the storm of March 1938.

We are probably all familiar with the devastation caused by the waves of mud and debris which swept down in the Tujunga-La Crescenta-Montrose-La Canada area during the New Year's 1934 flood. Those of us in this locality remember the volumes of silt, sand, and boulders which were deposited on streets and sidewalks, in parkways, and in yards. It was estimated that this deposition amounted to 659,000 cubic yards.

This year nine debris-basins controlling a major portion of the same watershed impounded 541,000 cubic yards of debris, or over 82 per cent of the total of that which came down during the New Year's flood. Without the protection afforded by the debris-basins and concrete channels, a repetition of the disaster of the previous flood in the Montrose-La Crescenta and Glendale areas would probably have occurred.

Rates of erosion in excess of the design-rate of 100,000 cubic yards per square mile of denuded watershed occurred during the March 1938 storm. Depositions in Shields and West Ravine Debris-Basins amounted to 120,000 and 118,000 cubic yards per square mile, respectively. These rates were from areas approximately 0.25 of a square mile in area. Rates from larger areas were somewhat less. Hall-Beckley Canyon, 0.84 of a square mile in area, produced debris at the rate of 111,000 cubic yards per square mile, while from Pickens Canyon, the largest individual watershed above a debris-basin, 1.84 square miles in area, the rate of erosion amounted to 82,000 cubic yards per square mile.

In calculating the capacity of a debris-basin, allowance is made for the debris which will be deposited on a slope back from the spillway. Sometimes there is a question as to what that debris-slope will be. The slope attained at Pickens Debris-Basin during the March 1938 storm was of interest in this connection.

The distance between the spillway-lip and the floor at the top of the inlet-structure in this basin is 516 feet; the gradient is 3.25 per cent. A profile of the debris-deposition after the flood showed that for the first 160 feet upstream from the outlet-structure the debris had been deposited on approximately a two per cent slope. At this point, however, there was an abrupt change in gradient to a seven per cent slope with the result that at the top of the inlet-structure the debris was 12 feet deep. The normal channel-gradient above the inlet-structure is approximately seven per cent; consequently, as debris was deposited in the basin on a slope paralleling that of the natural channel, a progressive lifting of the channel-floor took place upstream. It was estimated that over 40,000 cubic yards of debris were deposited in the channel above the basin due to the debris-slope attained.

From this experience, it is evident that, in those debris-basins constructed below the canyon-mouths where there are no canyon-walls to confine the flow, the design-gradient between spillway-lip and top of inlet-structure should be equal to, if not greater than, the normal channel-gradient upstream from the basin; otherwise, channel-deposition might lift the streambed entirely out of its banks with the possibility of the flood-flows being diverted sufficiently to by-pass the basin.

The storm of March 1938 not only brought down a large debris-flow into the debris-basins in the County but it also moved the greatest total volume of debris into the District's reservoirs that has been recorded to date. In the 15 District reservoirs located in mountainous areas, surveys made immediately after the flood showed that their total previous spillway-capacity, based on most recent surveys, had been reduced 12.4 per cent. The total loss of capacity amounted to 10,855 acre-feet. It is believed that the major portion of this loss occurred during the March 1938 flood.

Siltation-losses in individual reservoirs ran from a three per cent loss in storage at Thompson Creek Reservoir to 83 per cent in Sierra Madre Reservoir. The largest volume of debris was impounded in the reservoir behind San Gabriel Dam No. 1. This reservoir, with an uncontrolled watershed-area of 161 square miles, impounded over 5,200 acre-feet of debris up to spillway-elevation during the storm, or approximately 10 per cent of the original capacity. Since the dam had been completed just prior to the flood, this figure represents the actual loss in storage caused by the storm.

The seriousness of a rate of siltation such as this is obvious when one considers that channel-construction in the valleys below is predicated on the regulating capacity of flood-control reservoirs in reducing peak-flows. As a result of the March 1938 storm, four of the 15 District reservoirs lost over 50 per cent of their original capacity; five others lost between 25 and 50 per cent; and of the remaining six, five lost over nine per cent.

In addition to obtaining the volume of debris in each of the District's reservoirs during the March 1938 flood, an inspection was made of the channel-conditions above spillway-elevation to estimate the amount of debris which, having been deposited upstream from the reservoir, could reasonably be expected to move into the reservoir with the next season's runoff. This amount varied considerably for each of the reservoirs. Debris-deposition tailed out for a considerable distance upstream in Big Tujunga, Santa Anita, and San Dimas reservoirs, while in Pacoima Canyon practically all of the debris was deposited below spillway-elevation, considerable scouring having taken place in the stream-bed above.

At the time of observation, shortly after the storm, low-water flows were gradually moving the upstream-deposits into the reservoir. It was estimated that 1774 acre-feet of debris deposited in the reservoirs and channels above spillway-elevation could be expected to add to the siltation-losses caused by the March 1938 flood. In this connection, a survey made in October 1938 of the capacity of San Gabriel Dam No. 1 reservoir shows that already 950 acre-feet of debris have been carried from deposits upstream into the reservoir below spillway-elevation.

The average rate of erosion from the watersheds above the District reservoirs is estimated to have been 51,000 cubic yards per square mile including the channel-depositions just mentioned. The drainage-area back of Eaton Wash Dam produced the highest rate, amounting to 83,000 cubic yards per square mile from the 9.5 square miles of watershed. The lowest rate, 12,000 cubic yards per square mile, came from the 3.9 square miles of drainage-area back of Thompson Creek Dam.

From the foregoing facts and figures it is apparent that debris-control in Los Angeles County is a necessity, particularly in those local areas where communities have been built in the paths o debris-movement. It is believed that the methods which have been adopted have proven to be a satisfactory means of control.

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## DISCUSSION

**FRANKLIN THOMAS** (California Institute of Technology, Pasadena, California)--There is one point that I would like to clarify. Mr. Kenyon stated that in some instances spillway deposit-basins are raised somewhat above the ordinary elevation and the outlets and then I understood him to make the statement that, in view of the gradients which take place in the debris-basins, there is a correspondence in the gradients of the canyon. I wonder in those spillways which are built up above that elevation if there is not some variance of your established principles of design for a good basin?

**E. C. KENYON**--That is probably true. To offset that it would require that the channel-entrance of the basin take care of the debris-deposits that would occur.

**WILLIS C. BARRETT** (Soil Conservation Service, Glendora, California)--Do I understand that the debris-removal is carried on to be ready for the next flood?

E. C. KENYON--That is correct. That is done within the year dependent upon all the circumstances. Immediately after the water drains off of the debris-basin, we get a steam-shovel in there as soon as possible. It takes from two to three months for the larger basins and a much shorter period for the smaller basins. It depends, of course, on the volume of the debris in the debris-basin.

HAROLD CONKLING (Deputy State Engineer, Sacramento, California)--Approximately what is the cost of removing that debris?

E. C. KENYON--That varies from around 28 to 32 cents a yard, depending on the haul. If we can dispose of it right at the dam-site, the cost is considerably reduced over that where we have to haul it three or four miles. It probably averages 30 cents a yard.

L. M. WINSOR (United States Bureau of Agricultural Engineering, Salt Lake City, Utah)--I have been very much interested in this most excellent presentation of this subject. I have also been very much interested in the work that you have been doing in this section of the United States for the past 15 or 20 years. I have been watching it while we have been working with similar problems in Utah. I think I agree with the deductions which have been made with one exception. I believe the statement was made that it costs more to raise the structure high enough to keep the debris back than it does to remove the debris from these basins. We have worked with this problem for a long time in Utah and we have reached the final conclusion that we are able to fill the debris-basins high enough to store the entire flood-deposits at a cost as low as a half cent per cubic yard as compared with 20 to 30 cents per yard for removing the debris from the basin. We have done this by means of raising the barrier year after year instead of holding the cross-level at a constant elevation after the flood has deposited the basin full of debris to the present level. When the crest is raised, then the dykes or embankments are raised correspondingly high enough to hold the next flood, and in that way we can keep ahead of it so that we never have to carry any of that material out except enough to use in raising the embankment. We have found this method very successful.

As a means of raising the spillways, the spillway-crests are raised at successive elevations by stepping up the stream a little at a time. In this way we have built structures as high as 100 feet above the stream-bed and we have them in successful operation at this elevation. I believe that you might do well in this section of the country if you would investigate a little further the possibility of increasing the capacities of your debris-basins by making some real depositories out of them.

E. C. KENYON--One of the reasons that comes to my mind for not doing this is the location of those basins. They are primarily in areas that somewhat prevent the spreading out which would be necessary in raising the height of the dams. If we were to spread out to where we would take in the side hills, it would include, in a good many instances, considerable valuable property which, again, would complicate matters.

L. M. WINSOR--I went over some of your work following the March 1938 flood. In a few of those cases it occurred to me that you had quite a good opportunity of raising the elevation of your dykes and overflow-structures by depositing the material that is being hauled out of these basins along the valley that is already established. It seems to me it would be possible to increase very materially the crest of those basins. I have discussed this matter in a paper presented before the American Society of Civil Engineers at their meeting in Salt Lake City this summer. It has been published in the October 1938 number of the Civil Engineer if you care to refer to it.

M. P. O'BRIEN--One cannot help but make some comment on each of these when they are discussed because if the aims of the Los Angeles Flood-Control District and the Army Engineers are achieved, the next great problem will be to restore the beaches. Some of that debris undoubtedly naturally cover the valley-floor and a great amount of it goes to the ocean. In the flood of March 1938 there was a great amount of that material brought down onto the beaches and, of course, that meant a great deal of work for the engineers to restore the beaches after the flood-control matter is attended to. This could go on and on, but it seems to me it is a matter that should be given more consideration than it has been given in flood-control development.

## Afternoon Session, December 16, 1938

The second session of the South Pacific Meeting, American Geophysical Union, Section of Hydrology, was called to order at 2:00 p.m., F. J. Veihmeyer acting as Chairman.

# HYDRAULIC DESIGN OF FLOOD-CONTROL BASINS AND CHANNELS

James G. Jobes

Mr. Huberty asked that I bring out the special problems relating to flood-control in Southern California, and I was assigned the comprehensive subject of "Hydraulic design of flood-control basins and channels." I believe this covers a rather broad field and overlaps and includes, in a general way, the entire programs outlined for today and part of tomorrow.

Before designing channels or flood-control basins, it is necessary to develop (1) the hydrology and (2) a general plan of attack.

In developing a general plan, certain limitations, physical and economic, are unavoidable. Consideration must be given to availability of right-of-way to construct or enlarge channels to carry the design-flood. Availability of storage for the reduction of flood-peaks must be investigated. In the Los Angeles area, it was apparent that storage must be provided due to the restricted right-of-way for the Los Angeles River from Dayton Avenue downstream through the business and industrial sections of the city. It has been common practice to look first to the mountain-areas for flood-control storage. However, a careful study has revealed a lack of suitable dam- and reservoir-sites with sufficient storage to produce any appreciable effects on the flood-peaks through the highly developed sections. The loss of storage by the accumulation of debris and the disadvantages of control at points far distant from the area to be protected have led the United States Engineer Department to give consideration to construction of flood-control basins in the valley-areas.

In Southern California, the short flood-periods and sharp peaks have a material influence on all hydraulic design. This type of flood increases the desirability of providing flood-control basins, as only comparatively small storage is needed to greatly reduce the flood-peaks, thereby decreasing both the channel-sizes and the degree of protection that would be needed to

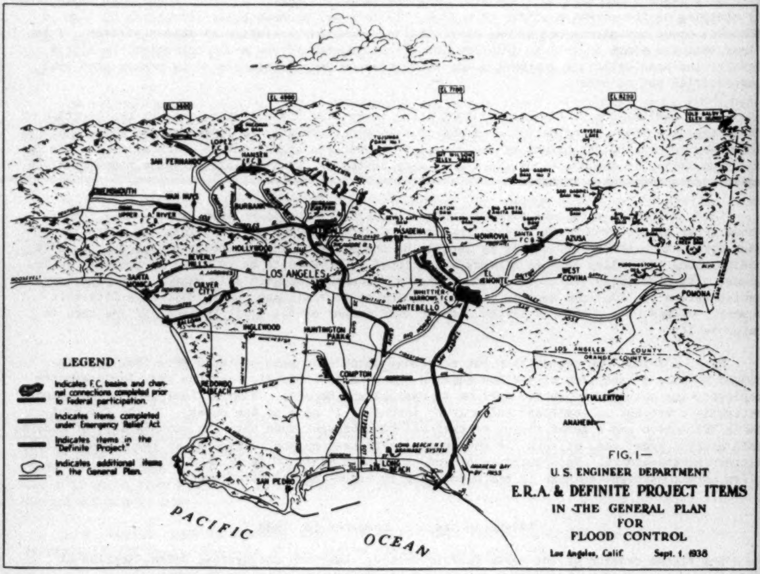

EL 4900
EL 7100
EL 8200
OLD BALDY ELEV
LOPEZ F.C.B.
SAN FERNANDO
HANSEN F.C.B.
LA CRESCENTA
TUJUNGA DAM No 1
MT WILSON ELEV
SAN GABRIEL DAM No 2
SAN GABRIEL DAM No 1
CRYSTAL LAKE
CHATSWORTH
VAN NUYS
UPPER L.A. RIVER F.C.B.
BURBANK
PASADENA
MONROVIA
SANTA FE F.C.B.
AZUSA
HOLLYWOOD
BEVERLY HILLS
SANTA MONICA
CULVER CITY
LOS ANGELES
EL MONTE
WEST COVINA
WHITTIER NARROWS F.C.B.
MONTEBELLO
POMONA
INGLEWOOD
HUNTINGTON PARK
LOS ANGELES COUNTY
ORANGE COUNTY
COMPTON
REDONDO BEACH
FULLERTON
ANAHEIM
LONG BEACH
SAN PEDRO
LONG BEACH H.E. DRAINAGE SYSTEM
ANAHEIM BAY
PACIFIC OCEAN
LEGEND
Indicates F.C. basins and channel connections completed prior to Federal participation.
Indicates items completed under Emergency Relief Act.
Indicates items in the "Definite Project."
Indicates additional items in the General Plan.

FIG. 1—
U.S. ENGINEER DEPARTMENT
E.R.A. & DEFINITE PROJECT ITEMS
IN THE GENERAL PLAN
FOR
FLOOD CONTROL
Los Angeles, Calif. Sept. 1. 1938

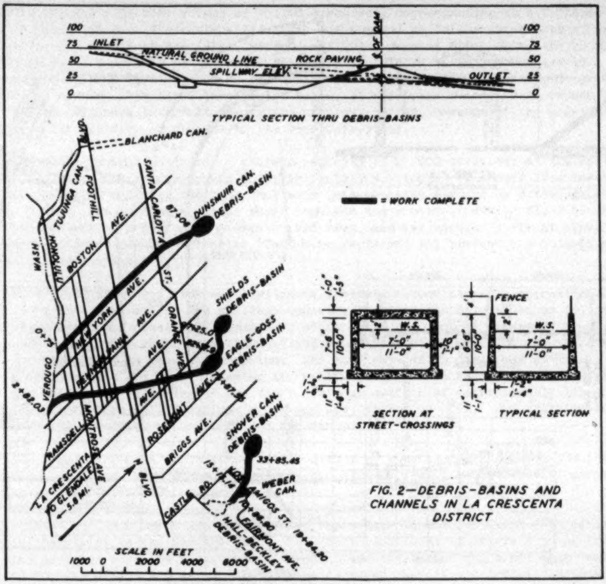

100
75 INLET
NATURAL GROUND LINE
ROCK PAVING
℄ OF DAM
50
SPILLWAY ELEV.
25
OUTLET
0
TYPICAL SECTION THRU DEBRIS-BASINS
BLANCHARD CAN.
= WORK COMPLETE
WASH
HOLLOW
TUJUNGA CAN.
FOOTHILL
BOSTON
AVE.
SANTA CARLOTTA
ST.
DUNSMUIR CAN.
DEBRIS-BASIN
NEW YORK
AVE.
SHIELDS
DEBRIS-BASIN
EAGLE-GOSS
DEBRIS-BASIN
ORANGE AVE.
VERDUGO
0+75
2+82.03
RAMSDELL
MONTROSE AVE.
ROSEMONT
AVE.
BRIGGS AVE.
SHOVER CAN.
DEBRIS-BASIN
33+85.45
WEBER CAN.
LA CRESCENTA
TO GLENDALE
5.8 MI.
N
BLVD.
CASTLE RD.
FAIRMONT AVE.
HALL-BECKLEY
DEBRIS-BASIN
SCALE IN FEET
1000 0 2000 4000 6000
FENCE
W.S.
7'-0"
11'-0"
10'-0"
SECTION AT
STREET-CROSSINGS
TYPICAL SECTION

FIG. 2—DEBRIS-BASINS AND CHANNELS IN LA CRESCENTA DISTRICT

safeguard the highly developed urban areas against the high velocities and destructive forces of a major flood.

After development of a general plan, it is necessary to make a detailed economic study, taking into account the benefits, advantages, degree of protection afforded, and practicability, to ascertain the exact channel- and reservoir-capacities to be provided. The items of the general plan, the construction of which has been authorized by the Flood-Control Act of 1936, are shown in Figure 1. The pivotal features of the plan are the four flood-control basins: The Hansen and the Sepulveda (formerly referred to as the Upper Los Angeles River Flood-Control Basin) on the Los Angeles River, and the Santa Fe and Whittier Narrows on the San Gabriel River. The primary function of these basins is the reduction of the design flood-peaks, so that adequate and safe channels can be constructed with the least disturbance to existing development.

The design of flood-control basins and channels in the Los Angeles area involves many hydrological and hydraulic characteristics which are not commonly encountered in other parts of the United States. The critical period of the floods usually does not exceed one to two hours' duration. For this reason the discharge of the maximum 24 hours practically dictates the entire design. This condition has been confirmed by a detailed study of the theoretical factors relating to the worst probable meteorological condition, and by records of past floods and the storms which produced them. The March 1938 storm followed the design storm-pattern very closely. The high rates of runoff and the short duration of the flood render it necessary to reserve as large a volume of storage as possible for use during the critical period. This, in general, dictates a gate-control instead of an automatic regulation by means of open ports. Detailed analysis has shown that the regulated outflow for a given storage may be reduced 10 to 25 per cent by use of gate-regulation as opposed to the use of open ports.

In the design of a flood-control basin the number and size of gates and the spillway-capacity are determined from one of the three following hydrographs: (1) The reservoir-design flood, (2) the computed spillway-flood, and (3) the spillway-design flood.

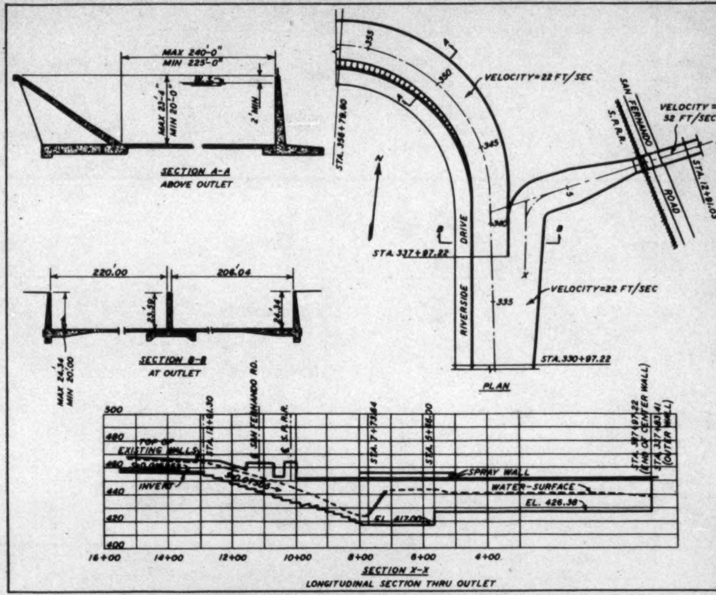

MAX 240'-0"
MIN 225'-0"
W.S.
MAX 23'-4"
MIN 20'-0"
2' MIN
SECTION A-A
ABOVE OUTLET
220.00
206.04
23.50
24.34
MAX 24.34
MIN 20.00
SECTION B-B
AT OUTLET
355
350
345
340
335
VELOCITY=22 FT/SEC
STA. 358+78.80
N
STA. 337+97.22
RIVERSIDE
DRIVE
SAN FERNANDO
S.P.R.R.
ROAD
VELOCITY = 32 FT/SEC
STA. 12+81.03
X
B
VELOCITY=22 FT/SEC
STA. 330+97.22
PLAN
500
480
460
440
420
400
TOP OF EXISTING WALLS
INVERT
STA. 12+81.30
SAN FERNANDO RD.
S.P.R.R.
STA. 7+73.64
STA. 5+56.00
SPRAY WALL
WATER-SURFACE
EL. 426.38
EL. 417.00
STA. 337+97.22 (END OF CENTER WALL)
STA. 337+83.41 (OUTER WALL)
16+00
14+00
12+00
10+00
8+00
6+00
4+00
SECTION X-X
LONGITUDINAL SECTION THRU OUTLET

FIG. 3—LOS ANGELES RIVER IMPROVEMENT, DETAILS AT THE VERDUGO OUTLET

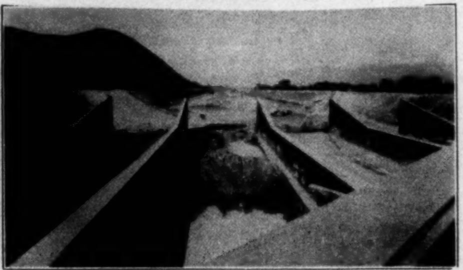


FIG. 4—LOS ANGELES RIVER AT LOS FELIZ BOULEVARD; VIEW OF UPSTREAM PIER-EXTENSIONS CONSTRUCTED FOR STABILIZATION OF FLOW UNDER THE BRIDGE

The reservoir-design flood is defined as the maximum flood that the reservoir is designed to control under assumed conditions of operation. The computed spillway-flood is the flood derived from a forecast of the worst storm using the highest runoff-factors and the worst runoff-producing combination for the drainage-areas in question. The spillway-design flood is that derived from the addition of a factor of safety to the computed design-flood.

In the design of the Hansen Flood-Control Basin, the reservoir-design flood was based on an assumed maximum 24-hour rainfall varying from 6 to 16 inches over the watershed, having a mean of 10.4 inches. The reservoir-design flood resulting from this rain has a peak-inflow to the Hansen

Basin of 64,800 cfs and a 24-hour volume of 45,000 acre-feet, corresponding to 5.7 inches of runoff from 147.4 square miles. The maximum flood-day was assumed to follow three days of preparatory rain producing a runoff on the first, second, and third days of 6500, 6900, and 12,500 acre-feet, respectively. A summation of the total four days of rain in the storm equaled 16.1 inches, and the corresponding four days' runoff of the design-flood equaled 70,900 acre-feet, or 9.0 inches depth. In routing this flood through the basin, it was found necessary to reduce the routing periods to 10-minute intervals during the critical period, because of the short duration of the flood and the rapidity of changes in the reservoir-stage.

The Hansen Flood-Control Basin has a storage-capacity of 27,600 acre-feet at its spillway-crest (elevation 1060), which corresponds to approximately 3.5 inches of runoff from the tributary drainage-area. Detailed routings indicate that with this capacity eight 5 by 8 feet gated conduits and two 8 by 6 feet ungated openings would regulate the reservoir-design flood to 12,000 cfs. The gated outlets were placed at elevation 995 feet, and the ungated ports at elevation 1011 feet, in order to provide some conservation (3400 acre-feet) and yet prevent the objectionable feature of hold-over storage.

The width of the Hansen spillway was limited by foundation-conditions to approximately 300 feet. Subject to this limitation, the spillway-capacity required was determined as follows: The computed spillway-flood was developed, based on a storm of 25 per cent in excess of that of the reservoir-design storm. The computed spillway-flood had a peak of 87,500 cfs. By increasing this flood by 50 per cent, both in peak and in volume, the spillway-design flood was obtained. Routing this latter flood over the spillway, assuming the reservoir filled to the spillway-crest and the outlets all blocked at the beginning of the flood, gave an outflow of approximately 100,000 cfs with a surcharge of 22 feet at the maximum water-surface, elevation 1082. The addition of 5 feet freeboard placed the elevation of the crest of the dam at 1087 feet.

Unusual problems were also encountered in the design of channels leading from the canyon-mouths to the valley-floor. The steep slopes produced extremely high velocities and subcritical depths for the entire range of discharges.

Figure 2 shows the location of the Dunsmuir and Eagle-Goss channels leading from canyons in the San Gabriel Mountains to the Verdugo Wash. The great quantities of debris issuing from the canyons in time of flood make it imperative to construct debris-basins which act in a dual capacity of a trap for the debris and as an inlet to the improved channel. A typical section of a debris-basin is shown at the top of the Figure. The design-debris capacities and the quantity of debris produced in the 1938 flood have been very ably presented by Mr. Kenyon in his paper. The canyons above the debris-basins produce runoff varying from 3000 to 5000 cfs per square mile. The channels leading from the debris-basins have slopes varying from 15 per cent in the upper reaches to five per cent in the lower reaches. The resulting velocities vary from 40 to 70 feet per second.

Verdugo Wash serves as a collecting channel for mountain- and foothill-areas lying above the city of Glendale. The area (27.1 square miles) tributary to this channel has estimated discharges from the design-storm varying from 30,000 cfs at its head to 39,000 cfs at its lower end. The channel was limited to a width of 43 feet in its upper reach by existing water-supply reservoirs through which it passes, and to 87 feet in width in its lower reaches by the limited right-of-way available. The alignment was extremely sinuous in its lower reach with numerous bends having radii varying from 1250 feet to 3700 feet. The computed depths for this reach vary from 7.9 to 9.3 feet, with velocities of from 50.6 to 53.9 feet per second.

The high velocities and sharp bends raised serious questions as to the freeboard to provide for superelevation and the losses to be expected. The usual textbook formula

$$\text{Difference in W. S.} = v^2b/gR$$

gives as superelevation one-half of the value obtained from this formula. Instead of using one-half the difference in W. S. as the superelevation, the full value was allowed, and an increased height of wall provided on both the inside and outside of the bend, and also carried to the beginning of the next bend below. The computed superelevations varied from 2.1 feet for the longer radius curve to 6.3 feet for 1250-foot radius curve. The experiments conducted by Professor Knapp for the Los Angeles County Flood-Control District indicated that the allowances provided were approximately correct, and that deflected waves within the bend and for considerable distances downstream could be expected.

The volume of discharge and the high velocities of the Verdugo channel at its entrance to the Los Angeles River necessitated the design of a special structure to reduce the velocity and bring the flow approximately parallel to that in the main channel. The stilling-basin design and junction-structure are shown on Figure 3. The velocity is reduced from 52 feet per second to approximately 22 feet per second, and the flow turned parallel to that in the river in approximately 800 feet.

The design-discharges for the Los Angeles River as modified by the flood-control basins vary from 40,000 to 87,000 cfs for the reach now completed between Niagara Street and Dayton Avenue (a distance of approximately 9.5 miles).

Channel-stabilizers have been provided in the trapezoidal channels, consisting of steel and concrete cut-offs extending across the channel and well into the banks, protected by grouted derrick-stones below.

Of special interest is the innovation at the Los Feliz Boulevard bridge. The footings for this bridge were not of sufficient depth to permit lowering the channel grades and sufficient clearance was not available under the bridge to permit passage of the design-discharge. This problem was solved by extending the piers upstream so as to eliminate the extreme skew presented by the existing piers and to produce the increased depth upstream of the bridge. A steep drop to insure flow below critical and through the bridge was provided. This structure performed nicely during the 1938 flood and prevented probable damage to the structure. The completed structure is shown in Figure 4.

United States Engineer Office,
Los Angeles, California

## DISCUSSION

F. J. VEIHMEYER (University of California, Davis, California)--I would like to ask Mr. Jobes, in his design of flood-control channels and other structures, what he takes into account. Does the character of the watershed, the topography, and the type of vegetation play any part?

J. G. JOBES--That would come under the development of the runoff. We take these things into consideration in developing runoff-curves for rainfall. However, as a matter of safety, the slope of the drainage-area is taken into consideration more than the cover to protect against possible burns. In southern California the floods are produced by short-period intense rainfall which becomes so high that the cover has but a minor effect.

## SILT PROBLEMS OF THE WEST

J. C. Stevens

We are at the beginning of a rapidly expanding program of reservoir-construction for multiple purposes of irrigation, power, flood-control, domestic water-supply, and silt-abatement. We may safely anticipate that this program will continue to expand until virtually all reservoirs for which there is a need and an economic justification will be created and placed in operation. We may speculate that the peak in this program will be reached in about 100 years.

By that time irrigation-development in the West will have reached its optimum. Practically all available areas that are suitable and for which irrigation is economically justified, and many that are not, will be under irrigation. This increase in irrigated areas over that existent today will be by waters conserved in storage-reservoirs. Under this optimum condition, populations will have trebled or quadrupled. Cities will exist where deserts now abound. Transportation, communication, and power-systems will join urban and rural areas with closely woven networks, and western civilization will have found its place in the Sun.

By that time many of the reservoirs now in use will have become useless by siltation and the program of supplanting them by other sites or by increasing storage-capacities by increasing the height of dams will have been well begun. This program of supplanting useless reservoirs will run parallel with that of constructing new ones and we may speculate that this dual program of construction and supplantation will continue for a period of 200 years. During this period practically all feasible reservoirs will have been constructed and western civilization will be faced with the problem of maintaining their usefulness by all means that ingenuity can devise.

We may visualize all sloping lands terraced, all bottom lands adequately drained, drainage-basins intensively managed to reduce erosion to a minimum, and economies practiced in the use of water that today are little dreamed of. Western civilization will be on the defensive with many casualties in its wake.

We may speculate that 500 years of this brave defense cannot end otherwise than in ultimate defeat; that ultimately all reservoir-sites will have been utilized and ultimately filled with the sediments from their drainage-basins; that ultimately western civilization must decline to a state which the unconserved waters of the West will maintain.

It is a rather dark picture but is it not the way of all flesh? Civilizations have been founded, have grown to an optimum of prestige and influence, and have gradually declined and faded to exhaustion. Of such were ancient Sumaria, Chaldea, Mesopotamia, and the Incan and Aztec civilizations in our own hemisphere. In many places of the West are found remains of irrigation-institutions once vigorous but now extinct.

The causes of these declines have been varied--foes from without and foes from within. Every civilization seems to contain the germs of its own disintegration. Exhaustion of natural resources must be recognized as a most potent cause, and if western civilization in the United States is not exhausted beforehand by other causes it most likely will become so by sedimentation of reservoirs before 40 generations have passed on.

The construction of storage-reservoirs in the West began scarcely 50 years ago and already a goodly number have either become useless or have had their usefulness greatly impaired by siltation. In Table 1 are included those in the United States, on which actual silt-surveys have been made, that have lost 50 per cent or more of their original capacity. Channel-reservoirs created by diversion-dams are not included.

Table 1--Storage-reservoirs in the United States that have lost 50 per cent or more of their original capacity

| Reservoir | Stream | Original capacity[1] 1000 af | Year constructed | Year of last survey | Siltation-period, years | Capacity lost, per cent |
|---|---|---|---|---|---|---|
| McMillan | Pecos | 90 | 1894 | 1932 | 39.0 | 56 |
| Old Lake Austin[2] | Colorado River of Texas | 49 | 1893 | 1900 | 6.75 | 48 |
| New Lake Austin | Colorado River of Texas | 32 | 1913 | 1926 | 13.0 | 96 |
| Boysen | Big Horn | 16 | 1911 | 1924 | 13.0 | 80 |
| Zuñi | Zuñi | 15 | 1906 | 1932 | 26.2 | 77 |
| Furnish | Umatilla | 5.5 | 1909 | 1931 | 22 | 82 |
| LaGrange | Tuolumne | 2.3 | 1895 | 1931 | 36 | 83 |

[1] To spillway-level or level controlled by flashboards or crest-gates.

[2] Dam failed in 1900; reconstructed in 1913.

Can we do anything about it? Ultimately, no. But we can postpone the evil day. If, instead of waiting until we are on the defensive we begin now to adopt those measures we know must eventually be adopted, we might hold this civilization intact for several hundred years longer than would otherwise be the case. Every decade that can be added to the useful life of a storage-reservoir is abundantly worthy of accomplishment, because there is so much at stake.

The measures now being taken by the Soil Conservation Service, the Forest Service, and other Federal and State agencies are pointing the way. We have, however, just begun. Many practices now followed will be found futile and others more effective will be substituted. Only by experience can we prove or disprove theories. Progress will only be made by patient endeavor and many backward slips must be expected.

Two types of erosion must be recognized: The type that has gone on since the foundations of the Earth were laid; the type that has moulded hills, mountains, and plateaus to their present configuration and has built up valleys and bottom land; the type that levels uplands to plains and renders them fit for human occupancy we may style geologic erosion. We need not concern ourselves much with this type of erosion for there is little we can do about it. We must not even wish to halt the normal phases of this process.

The other type of erosion is largely man-induced. We may call it cultural erosion. It results from man's improvident use of land- and water-resources. Every highway, every irrigation-canal, every railroad, the grazing of livestock, the cultivation of fields--in short, every scar made by man on the Earth's surface is a source of incipient erosion that in critical areas may reach serious proportions, and greatly aggravate the normal geologic erosional processes. It is to this type of erosion that preventive and remedial measures must be applied to lessen its expansion and to heal the scars that have already been made. We cannot expect to eliminate entirely this type of erosion any more than we can hope to do away with cultural activities. Nevertheless, nature will work wonders in healing scars if given a chance. The maintenance of an adequate vegetal cover is the most important single consideration. Correct methods of tillage and farm-management, the control of grazing, the protection of forests from fire and improvident cutting, the searching out of plant-types that will thrive in critical areas, and the revegetation and protection of those areas are factors essential to a well-balanced and orderly program to reduce cultural erosion to a minimum.

The efficacy of these measures, however, must not be unduly exaggerated for the claims as to their value can only be proven by catastrophic trials such as that visited upon Southern California during the downpours of March 1938. One of the dangers to be reckoned with is that such cloudbursts may bring down not only the silts and debris normal to such a storm but those accumulated over many preceding years and held in reserve by inadequate and improperly maintained detention-works and measures. That has actually happened in many instances in the West where unproven detention-works were hastily built.

I have asked many of my friends in the Soil Conservation and Forest services this question: "If you could put into immediate service all the soil-retention measures that have proven effective and can be economically justified throughout the entire drainage-area of Colorado River, how much of the 200 million tons of silt now carried annually to the gulf or stored in reservoirs could be held on the basin-area?" The answers have varied all the way from 40 to 95 per cent. My own feeling is that 15 or 20 per cent would be more in accordance with the truth. Even that much would be abundantly worth while as it would add between 100 and 200 years to the useful life of the Colorado s reservoir-system. I challenge anyone to adequately evaluate a reprieve of 200 years to western civilization.

What is silt and where does it come from? Silt is rock-ravelings and comes from the disintegration of rocks. Rain-water dissolves certain rock-constituents; it enters crevices, freezes spalls off particles and blocks; chemical agents in air and water react with those in the rocks causing them to break down and crumble to dust. Rocks in stream-beds are ground to sand and the chemical constituents dissolved and carried away. Sedimentation is that phase of the geologic cycle involving water-transportation and deposition. Lakes and valleys are filled, great deltas extend fan-like into oceans creating alluvial plains. Of such are the valleys of the Nile, the Ganges, the Mississippi, the Yellow River, and our own Lower Colorado and Rio Grande.

In areas of abundant precipitation the streams carry off the detritus from rock-disintegration almost as fast as it accumulates. Such streams run clear except during floods. On the arid areas such detritus accumulates to great depth and may remain in place for many years until an unusual rainfall or cloudburst occurs when great quantities of silt are carried into stream-channels. If the drainage-area is large enough, such downpours occur in some portion of the drainage-area at sufficiently short intervals to keep the main stream surcharged with sediments. This characteristic is observed on the basins of the Colorado, Rio Grande, Missouri, and most streams of southern Texas.

The geological formations of which the basin is composed are also a most important factor. On the Yellow River the yellowish wind-born loess keeps the river supplied. On Rio Grande, Colorado, and Texas streams exposed sedimentary rocks are rapidly disintegrated, providing enormous quantities of fines for transportation by both wind and water.

Stream-degradation--A most fruitful source of silt in streams is bank-caving by which sediments are reworked or carried entirely off to the sea. An alluvial valley is built up during centuries of sedimentation and then degraded under a new set of cultural or climatic conditions. Valley-building appears to be an endless succession of alluviation and degradation.

Abundant evidences of these recurring cycles have been found. Two such instances will be cited taken from a report on "Erosion and control of silt on the Rio Puerco, New Mexico," by Kirk Bryan, Professor of Geology, Harvard University. Figure 1 shows how an alluvial valley is formed, and Figure 2 shows how it may be degraded.

| TOPOGRAPHIC DIVISIONS | MESA | CLIFF EDGE | HILL-SLOPE | ALLUVIAL FAN | VALLEY-FLOOR | CHANNEL-TRENCH (ARROYO) |
|---|---|---|---|---|---|---|
| VEGETATION | PINE, JUNIPER PIÑON | | JUNIPER, GRASS | GRASS AND SAGE | GRASS, WEEDS, GREASEWOOD | USUALLY BARREN GRASS AND WEEDS |
| RATE OF WEATHERING | SLOW | RAP. | RAPID | NO IMPORTANCE | NO IMPORTANCE | |
| RATE OF RUNOFF | FEEBLE | RAP. | RAPID | SMALL EXCEPT FROM HEAVY RAINS | RAPID | |
| RATE OF SILT-PRODUCTION | MODERATE | MOD. | MODERATE | SMALL UNLESS GULLIED | SMALL UNLESS GULLIED | EXCESSIVE, DUE TO LATERAL EROSION |

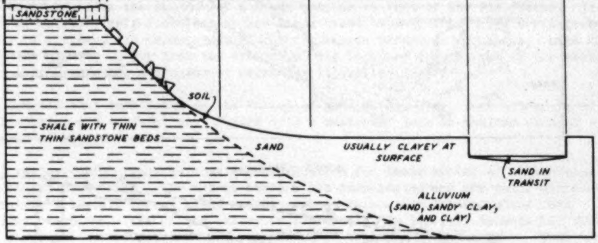
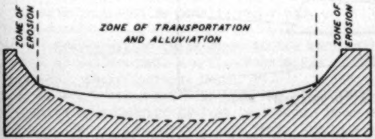
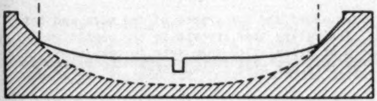


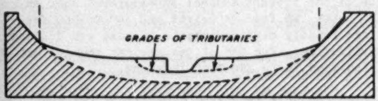
FIG. 1—HOW ALLUVIAL VALLEYS ARE FORMED



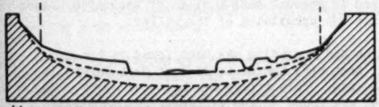
(A) CONDITIONS OF NORMAL EROSION OBTAINING IN FIRST HALF OF 19TH CENTURY



(B) CONDITIONS OF ABNORMAL EROSION INITIATED BY CUTTING OF ARROYOS IN THE LAST HALF OF THE 19TH CENTURY



(C) CONDITIONS OF INCREASING EROSION AS THE MAIN ARROYO WIDENS AND TRIBUTARY ARROYOS FORM



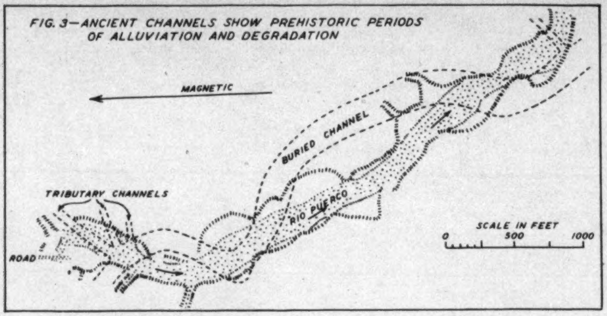
(D) CONDITIONS OF DECREASING EROSION WHEN A LARGE PART OF THE ALLUVIUM SHALL HAVE BEEN REMOVED

FIG. 2—HOW AN ALLUVIAL VALLEY MAY BE DEGRADED

The silts come mainly from the disintegration of cretaceous rocks that cover about one-half the drainage-area. The characteristic topography of the silt-producing areas consists of mesas underlaid by sandstone lying between broad valleys eroded in the shales (Fig. 1). The sandstone cliff is undermined by the more rapidly eroding shale and breaks off along joint planes. These pieces weather into sands, while the shale-base forms clays. The valleys become filled with fine argillaceous sands that are eroded easily unless held by grass-sod or other vegetation. Gullies are formed on the steep hillsides that end in deltaic fans formed by silts deposited at the valley-floor. These deposits form cracks when dried, creating vertical joint planes in the mass. When such deposits form the banks of a stream, they are easily undermined; the banks cave off in blocks, crumble, and become the suspended load of the stream.

Rio Puerco began degrading its valley-floor about 50 years ago. Figure 2 shows the successive events as they have been pieced together by historical inquiry and geological evidence. The silt derived from the valley-walls was carried over the surface and on downstream through discontinuous channels, intermittently by the floods. This condition is shown in Figure 2(a). With the cutting of the arroyos, the present period of abnormal erosion or degrading process began [Fig. 2(b)]. The rate of silt-production passes through a cycle. When the main arroyo is narrow and increasing in length upstream, the rate of silt-production is increasing. When it becomes a continuous channel, the widening process begins [Fig. 2(c)]. At this stage, the rate of silt-production has reached a

FIG. 3—ANCIENT CHANNELS SHOW PREHISTORIC PERIODS OF ALLUVIATION AND DEGRADATION



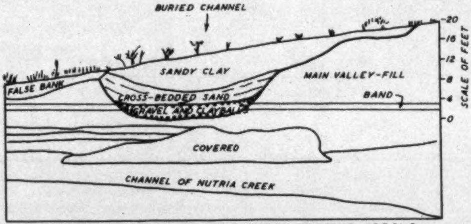


FIG. 4—ANCIENT CHANNEL EXPOSED IN PRESENT ARROYO

maximum. When the channel becomes so wide that the floods only touch its sides lightly or intermittently, bank-caving and consequent silt-production begin to diminish.

A time will come when the entire slice of alluvium above the new grades of the main and tributary arroyos shall have been removed [Fig. 2(d)]. The valley then reverts to the condition shown in Figure 2(a), but at a lower level. A process of alluviation then sets in that tends to build up the valley-floor to some higher level. After this has been accomplished, the cycle of degrading will be repeated.

Abundant evidences were found in the Valley of the Rio Puerco of earlier cycles of alluviation and subsequent degrading. Figure 3 is a sketch of the present channel superimposed over an ancient one. The present arroyo has nearly vertical banks, 25 feet in height and 180 to 500 feet apart. The outcrops of the buried ancient channel are readily distinguishable because its filling is lighter in color than that of the present valley-alluvium. The bed of the ancient channel was at about the same level as the present channel and varied from 75 to 220 feet in width.

Traces of other channels were found. These buried channels represent a period of erosion and degrading similar to that going on at present. Each was followed by a period of alluviation that completely obliterated traces of old arroyos and in general made a plain of the valley-floor over which the flood-waters could spread and continue the upbuilding of the valley.

Another famous example of a cycle of alluviation and degrading has been found in the Rio Chaco. At Pueblo Bonito, an arroyo from 150 to 450 feet wide and 25 to 30 feet deep exists at present similar in all respects to the one on Rio Puerco. This arroyo has been cut since 1860. Pottery and charcoal, to depths of 20 feet, or more, are found in the valley-alluvium showing that this alluviation occurred during its occupancy by prehistoric peoples. After Pueblo Bonito and other large pueblos were built and occupied, an arroyo was cut through the valley-floor and later filled by alluviation to its original level. Where this buried channel outcrops in the walls of the present arroyo, pottery of very recent occupancy is found, while at similar depths in the main valley-fill only pottery of much earlier periods has been discovered.

This ancient arroyo does not coincide with the present one, but is crossed, touched, and recrossed by it. The ancient channel may be traced for about five miles. It tells the same story of periods of degrading followed by periods of alluviation.

These ancient peoples probably subsisted largely by "flood-water farming." When the ancient arroyo was cut in the valley about the end of the Great Pueblo period, it rendered such farming methods impossible. This has been assigned by Professor Bryan as a possible reason for the abandonment of these Indian villages. A subsequent period of alluviation filled this arroyo and probably permitted reoccupancy. The present period constitutes another cycle of degradation.

The Zuñi River has been the subject of a study similar to that of the Rio Puerco. It is an ephemeral stream, carrying only flood-waters and large quantities of silt. The drainage-basin consists mainly of plateaus and mesas underlaid by cretaceous sandstone and shale. Like the Rio Puerco its silt is derived mainly from the erosion of the banks of arroyos cut in the valley-fill. This stream is also undergoing a process of degrading its valley-floor.

Ancient channels have been found in the Valley of Zuñi River, also, that attest to earlier periods of alluviation and degradation. Figure 4 is a sketch of such an ancient channel exposed in the high banks of Nutria Creek.

Causes of valley-degradation--No complete explanation for these cycles of alluviation and degrading has as yet been found. The potent factors are deep-seated and are quite certainly beyond Man's power to alleviate to any great extent, except in certain favored situations. During a period of alluviation the slope of the valley is flattened. In time, it becomes too flat for the stream to carry its normal flood-waters. A period of channel-cutting ensues. This process of degradation is carried beyond the balance point, and a period of alluviation sets in.

There are a few other problems of more or less local importance connected with the control of silt that will be briefly mentioned.

Retrogression below dams--At the meeting last fall in Davis I presented a paper, "The effect of silt-removal and flow-regulation on the regimen of Rio Grande and Colorado Rivers" (Trans., Amer. Geophys. Union, Pt. II, p. 653, 1938) in which it was shown that the retrogression of Colorado River below Boulder Dam since February 1, 1935, had extended for 60 miles and had reached a maximum of 20 feet in places, or an average lowering at section 2 near the dam of 10 feet. Subsequent surveys show that this retrogression continues but at a lesser rate. The total material removed from the river-channel for a 63-mile stretch below the dam in 1049 days was 18,138,000 cubic yards.

This lowering of the river entails problems involving bridges, canal headings, pumping plants, and other works along it that will appear whenever a reservoir is placed in operation on an alluvial stream. Withholding silt and converting the river from a muddy to a clear stream means a new regimen for thatstream which produces local problems of considerable significance.

Desilting irrigation-water is also a problem that has many phases in the West. A most notable example is the desilting works at Imperial Dam, the head of the All American Canal (Eng. News-Rec., p. 538, Oct. 17, 1935), that is expected to result in savings of a million or more dollars in the annual costs of maintenance and operation of the Imperial Irrigation District.

With such a regulated stream, however, the problem of disposing of the silt, returned to the river-channel from such works, has not yet been solved--only experience can do that, and these works are just beginning to function.

Complete removal of silt, however, would bring on another problem of the growth of aquatic plants in canals and laterals. Silt enough to exclude sunlight seems to be a requisite for preventing such weed-growth.

The building up of lands due to the long-continued use of silt-laden irrigation-water must also be reckoned with. The Nile Valley has been raised an average of four inches a century from annual inundations during the past 5000 years (Transactions Amer. Soc. Civ. Eng., v. 101, pp. 1012-1048, 1936). Cultivated areas in the valleys of the Lower Colorado and Rio Grande have been raised in some cases many feet from this cause. thus creating local problems of irrigation- and drainage-technique.

In some instances this silt has been a blessing in annually renewing the fertility of the soil. In others it has been a detriment wherever the deposits are lacking in humus.

In conclusion, I want to point out that the one great silt-problem of the irrigated West is that of preserving the integrity of our storage-reservoirs. All others are of local or temporary import and are quite capable of ultimate solution.

For the major problem, however, there now appears to be no final solution. Is the technical skill of humanity able to cope with it? How long can the day of exhaustion of our storage-facilities be postponed? Are the measures of soil-conservation, forestry, grazing control now in effect, accomplishing their expected purpose? Can Man be brought to a realization of the importance of remedial measures and will he, under some inconvenience and expense to himself, adopt them for the benefit of future generations?

The answers to these questions are of tremendous importance to Western civilization. They are so important that a special study of this problem, through broad cooperative effort, amply financed, should now be undertaken without further delay.

Spalding Building,
Portland, Oregon

## DISCUSSION

M. P. O'BRIEN (University of California, Berkeley, California)--There is this aspect on the whole matter. We have so many reservoir-sites that have possibilities for development. Perhaps the wise, long-range plan would be to wait and not develop them until they are really needed to such an extent that they can be justified economically rather than to rush the development. I believe we should have our civilization grow to correspond to our facilities and this generation would not have to think of 500 years from now when Mr. Stevens thinks we will have this real need.

TOM C. MEAD (United States Bureau of Reclamation, Boulder City, Nevada)--With regard to Mr. Steven's paper and the comments on it by Professor O'Brien, if there is a delayed program of reservoir-construction then we should lay out our reservoirs now. If we delay improvements on reservoir-sites, it will add greatly to the cost of developing them later. I have in mind, for example, Flathead Lake in Montana. There have been some villas built along the lake and then if the Government wants to raise the height of the lake later on, it will mean the repurchase of all the improvements and villas. They will have to pay condemnation costs if they want to construct reservoirs. Condemnation of roads, railroads, and improvements is one of the major features of the cost.

F. J. VEIHMEYER (University of California, Davis, California)--The question really comes back to economics again when we consider 200 or 150 years from now. We can write it off at the end of that time and still serve the purpose we had in mind by creating this storage.

## GROUND-WATER PROBLEMS IN THE SOUTHERN HIGH PLAINS

Walter N. White

(Published with the approval of the Director, U. S. Geological Survey)

### Introduction

The High Plains region has been passing through a prolonged low in the precipitation-cycle during a large part of the last decade. The drought has continued longer and has been more severe than any that has been experienced since the region began to be farmed. It has caused untold distress. Crops have failed for years in succession. In large areas in the so-called dust-bowl the top soil has been almost entirely removed by wind-erosion and the dust-storms have become so bad at times that the health of the inhabitants has been seriously threatened. In some parts of the region the annual rainfall, which ranges from about 18 to 24 inches, according to the location of the area, has returned to about the normal or long-time average. In others the drought is still in progress and a partial or complete crop-failure was again experienced in 1938. When the rainfall-record is studied, it becomes apparent that a large part of the High Plains never should have been farmed and should be allowed to go back to the range, if indeed the native grasses can be restored. Other parts, however, can still be farmed with moderate success by the farmer who uses proper methods of cultivation and crop-rotation, and combines farming with stock-raising by keeping a part of his land in pasture and raising mostly feed-crops. Irrigation, if it can be accomplished at a practicable cost, affords security both to the farmer and stock-raiser.

## Surface-water supplies

In the Southern High Plains, comprising the part of the region which lies to the south of the Arkansas River, there are only two large streams, the Cimmaron and the Canadian rivers. These streams afford opportunities for irrigation-development upstream in New Mexico and downstream in Oklahoma and Texas, but where they cross the High Plains they are so deeply intrenched that it is difficult to irrigate anything but low bottom-land from them, even if the streams were regulated so as to provide an abundant irrigation-supply. Most other streams of the Southern High Plains, including headwater tributaries of the Red, Brazos, and Colorado rivers, rise on the High Plains themselves. These streams are intermittent or ephemeral and carry water only during heavy rains and for a brief period thereafter, except in occasional stretches where ground-water maintains a small perennial flow.

In much of the region traversed by these streams the surface of the Plains is almost as level as a floor, the drainage is poorly developed, and comparatively little water reaches the streams. Either there is no runoff from such territory, or the runoff that does occur drains into the nearest sink or depression and forms a pond which slowly disappears. These sinks are of frequent occurrence on much of the Southern Plains. In some parts of Texas they have been mapped and found to average about one to the square mile. The sinks usually are less than one mile in diameter and less than 25 feet in depth, but some of them are much wider and deeper. The water which does reach the streams usually disappears before going very far, and only the largest runs of water persist beyond the eastern escarpment of the Plains. Texas engineers give only minor consideration to runoff from the High Plains. For example, it usually is held that the 11,500 square miles of High Plains attributed to the Colorado River drainage is practically nonproductive in runoff so far as economic uses are concerned. An example of the low rate of runoff from the High Plains is shown by the gaging records for Prairie Dog Fork of Red River, or Palo Duro Creek, during 1925 and 1926, two years of about average rainfall. The runoff amounted to only about one per cent of the rainfall on the drainage-area usually attributed to the stream by available maps. However, single floods on this stream and others have been known to carry more water than is discharged during an entire year of moderate runoff. Feasible reservoir-sites exist on some of these streams, and reservoirs have been constructed or are to be constructed on them in connection with the Farm Security program, but the possibilities of irrigating from them are limited.

## Ground-water supplies

Under the conditions mentioned, the ground-water resources of the region, which are not immediately affected by drought, are especially valuable. The reservoirs of ground-water beneath the Southern High Plains are very large. In most of the region, the water-table is too deep for practicable irrigation, or the water-bearing sands are too fine to yield sufficient water to irrigation-wells. But in parts of the region comprising the Southern High Plains in Kansas, Colorado, Oklahoma, Texas, and New Mexico, the water-table is relatively near the surface and the water-bearing sands and gravels yield water to wells in sufficient quantities for irrigation. Irrigation from wells has reached an important scale in the High Plains in all five of these States, but it has progressed further in the High Plains of the Texas Panhandle than anywhere else. The brief discussion which follows is devoted to the ground-water in the Texas High Plains. It is based mostly on information obtained by the Federal Geological Survey, or by the Geological Survey in cooperation with the Texas Board of Water Engineers.

Most of the usable ground-water in the Texas High Plains, as in all of the Southern High Plains, is found in the Ogallala formation, which lies at or near the surface throughout almost the entire region, in many places is between 200 and 300 feet thick, and in a few places more than 400 feet thick. The clays, silts, sands, and gravels of this formation were deposited in part by streams, most of which had their headwaters in the Rocky Mountains, and in part by the wind. The Ogallala rests on an uneven floor of older rocks which was eroded into valleys and ridges before its deposition. Nearly everywhere in the Texas High Plains the water encountered in these underlying rocks is highly mineralized and unfit for most uses.

The beds of the Ogallala formation once extended from the mountains of New Mexico eastward far into Texas, but they have been removed by erosion from much of the territory they once occupied. They now stand up almost like islands, being bounded by the escarpments of the Plains both on the east and on the west and being cut in Texas into two segments by the Canadian River, which is deeply entrenched in the older rocks. The Ogallala formation has been completely eroded away to the west of the western escarpment and to the east of the eastern one and from the canyon-like valley of the Canadian. The water-bearing sands and gravels of the Ogallala in both of these segments, therefore, are cut off in all directions from any underground connection except through the underlying older rocks which contain highly mineralized water entirely unlike the fresh water in the beds themselves.

Wells of large yield drawing from the sands and gravels of the Ogallala are of common occurrence on the Texas High Plains. The water is contained in small interstices between the particles of gravel and grains of sand. Although it is moving, generally in a southeasterly direction, the movement is very slow--perhaps at an average rate of 200 to 300 feet a year. Inasmuch as the water-bearing beds are cut off in all directions from outside sources of water except through underlying rocks containing poor water, it follows that the source of the fresh water must be entirely within the High Plains themselves, and must be the rain that falls on the surface of the Plains. Most of the rain-water is dissipated by evaporation or by transpiration of grasses, shrubs, and cultivated crops, but part runs off, either into the streams or into the depressions or sinks which are partly filled by each heavy rain. Recharge of the ground-water reservoir occurs by direct penetration and by seepage from streams and depression-ponds.

### Irrigation from wells in Texas High Plains

Irrigation from wells in this region was started more than 30 years ago near Portales, New Mexico, situated on the High Plains about 15 miles west of the Texas-New Mexico boundary. The development soon spread to near-by areas in Texas. During the World War there was a general decline in well-water irrigation due in part to the shortage and high cost of farm-labor and in part to the introduction of the tractor which encouraged cultivation and cropping of large tracts of land by dry farming methods. In the seven years following the war, 1919 to 1926, the rainfall in most of the region was above average and comparatively little irrigating was done. Interest was revived during a period of several years of low rainfall which began with 1927. In 1934 there were about 300 irrigation-wells in the High Plains. The rate of development, which had been relatively slow to 1934, increased materially in 1935. It was accelerated somewhat in 1936 and became still more rapid in 1937. A part of the wells that were put down from 1935 to 1937 were located in the older pumped areas but many of them were drilled in new territory.

More or less well-irrigation development has taken place in the following 14 counties: Hale, Floyd, Swisher, Lubbock, Lamb, Bailey, Deaf Smith, Castro, Hockley, Briscoe, Parmer, Crosby, Randall, and Dallam. The greater part of the development is between Lubbock and an east-west line 20 miles South of Amarillo. Altogether approximately 1150 irrigation-wells were pumped in 1937, and about 160,000 acres were irrigated from them. The yield of the wells ranged from about 300 to 2000 gallons a minute and averaged about 700 gallons a minute. Approximately 350 new irrigation-wells were brought into service in 1938 but only a part of the older wells were pumped. The total area irrigated from wells was somewhat greater in 1938 than in 1937. Grain, cotton, and feed crops are raised for the most part.

### Decline in the water-table and reduction of ground-water in storage

Since May 1937 the water-levels in about 800 wells in the Texas High Plains have been measured monthly or at other regular intervals. Records of single measurements of water-levels in a considerable number of wells in the pumping districts are also available for 1934, 1935, and 1936. These records show that there has been a general decline in the water-table in the principal pumping districts of the Texas High Plains during the last few years. The decline from 1934 to 1938 was from one to six feet in the areas of heaviest pumping. Although on the average the drop has been small, it has been spread over large areas and the total volume of formerly saturated material that has been unwatered by the decline is large. The water that has drained out as the water-table declined has moved downward to replace the pumped water, and represents a loss from the volume formerly in storage. This loss since 1934 apparently represents a considerable part of the pumpage. In other words, the water withdrawn during the last four years has come, in considerable part, from water stored underground prior to 1934.

### Ground-water recharge

In the course of the ground-water investigation in the Texas High Plains by the Geological Survey, in cooperation with the Texas Board of Water Engineers, a special effort is being made to estimate the amount of the ground-water recharge. The recharge is being studied by periodic measurements of water-levels in the observation-wells, many of which are located in areas that are not directly affected by pumping. Some of the observation-wells are near streams or depression-ponds and some are remote from any such features. Test-holes are being put down in large numbers in the flood plains of the streams and in the depressions. The results show that recharge takes place chiefly from the streams and depression-ponds and in sand-dune areas, but thus far it has not been possible to compute the amount of the recharge. More definite results have been obtained from the studies of the natural discharge. This occurs through seeps and springs along the eastern escarpment of the Plains and by evaporation and transpiration of plants in the valleys of the streams and in other places where the water is at the surface or within a few feet of it.

### Natural ground-water discharge

Before pumping was started, the ground-water reservoirs of the High Plains were in a state of approximate equilibrium, the average annual intake of water from rainfall being balanced by an equivalent annual discharge. This condition has probably not been disturbed to any considerable degree by pumping. Therefore, if the discharge can be measured, some idea of the average annual recharge can be obtained. In connection with the cooperative investigation, intensive studies of natural ground-water discharge have been made, both before and after killing frosts, in an area of the High Plains extending about 75 miles in a north-south trend along the eastern escarpment and about 120 miles from this line toward the northwest. The direction of the natural ground-water movements is southeastward. The discharge of the large springs was measured with weirs, and the discharge of the smaller springs and seeps and the discharge by evaporation and transportation were estimated. From the figures thus obtained, the discharge from the area has been estimated to be at the rate of about 25,000 acre-feet a year, representing only about one-twentieth of an inch over the 9000 square miles of the area. The figures are to be checked by repeating the discharge-measurements during the winter and early spring of 1938-1939.

### Artificial ground-water recharge

Can the ground-water recharge be increased by artificial methods? This is problematical. A number of attempts have been made in the Texas High Plains to put the water of the depression-ponds underground by means of wells for the purpose of drainage. A few were successful at first, but after a time the wells clogged up and would no longer take water. Low dams to hold back the flood-flow of the streams in those stretches where conditions are particularly favorable for deep percolation might be effective. Reservoirs of considerable size might serve to concentrate the ground-water recharge where such recharge is especially needed. The City of Amarillo has one such reservoir on Palo Duro Creek and recovers the water by means of wells adjacent to and below the reservoir. However, care must be taken that the natural conditions for deep percolation are not too greatly disturbed; otherwise the recharge may be decreased instead of increased, as the result of the deposition of silt in the reservoirs and even above low dams. A project is being considered in Dallam County, Texas, under the water-facilities program of the Farm Security Administration, for spreading of the flood-waters of Mustang Creek for pasture-irrigation in an area in which there are several pumping plants. If the project is carried out, the effect of the water-spreading on the water-table will be carefully watched. However, most of the uplands of the Texas High Plains and even the low terraces adjacent to the beds of the streams are underlain by thick deposits of caliche, which tend to check or wholly prevent deep penetration. In general, conditions on the Texas High Plains are not believed to be favorable for artificial recharge on a large scale by water-spreading or any other method.

U. S. Geological Survey,
Washington, D. C.

## Morning session, December 17, 1938

The Saturday morning session of the South Pacific Meeting, American Geophysical Union, Section of Hydrology, was called to order at 9:45 a.m., Samuel B. Morris, Dean of Engineering, Stanford University, California, acting as Chairman.

## FLOOD-CONTROL DUTIES OF THE CORPS OF ENGINEERS, UNITED STATES ARMY

Major Theodore Wyman, Jr.
Corps of Engineers, United States Army

The Corps of Engineers, United States Army, was not assigned official charge of Federal flood-control activities until the passage of the Flood-Control Act of June 22, 1936. However, prior to that date, the Corps prepared thousands of flood-control studies throughout the United States, and by special acts of Congress, 1910, 1917, and 1928, designed and constructed flood-control improvements on the Mississippi and Sacramento rivers. It may be of interest to learn the reasons why the Corps of Engineers, acting through the Chief of Engineers and the Secretary of War, became the agency responsible for the design and construction of flood-control works throughout the United States. The reasons are logical and are based upon the experience of many years.

Early records from the Minutes of the Continental Congress make mention of a Corps of Engineers, but the Corps was not formally established until March 11, 1779, when its identity was officially recognized by resolution of Congress. It was mustered out of service in November 1783, reestablished in 1794, and reorganized in 1802. The reorganization provided for a Corps of Engineers and a Corps of Topographical Engineers. Under this reorganization act, in 1802, the Corps of Engineers was charged with establishing and operating the United States Military Academy. This was the first technical or engineering institution of learning established in this country, and therefore was for many years the only source of engineers available to the new Federal Government.

In 1820, Congress appropriated the sum of $5000 for the purpose of surveys, maps, and charts of the Ohio and Mississippi rivers. This reconnaissance was made by three officers of the Corps of Engineers.

Improvement for navigation of rivers and harbors by the Army Engineers was first authorized by Act of Congress in 1824, when the sum of $75,000 was appropriated for the removal of snags in the Ohio and Mississippi rivers between Pittsburgh and the mouth of the Arkansas River.

Army Engineers were detailed to aid in location, construction, and operation of many of our great railway systems in the early part of the nineteenth century. The Corps of Engineers aided in locating the Baltimore and Ohio Railroad in 1827; and subsequently built and managed the Northern Central, Erie, New York, New Haven and Hartford, and many other railroads. The dates of these early railroad engineering activities are not well established. However, that work was concurrent with highway and road-building projects and further work on the Mississippi River when, in 1837, Congress made its third appropriation authorizing investigations by the Army Engineers. Again, late in 1850, Congress appropriated $50,000 for surveys of the Mississippi River; a difficult task, beset by many hardships, but ably completed by Captain Humphries and Lieutenant Abbott, officers of the Corps of Engineers.

In addition to the river and harbor work of the early years, the Engineer Department performed services which are now regular functions of the Lighthouse Service, United States Geological Survey, the Coast and Geodetic Survey, and other important activities now carried on by various agencies of the Federal Government.

The work of the Engineer Department expanded gradually with the settlement and development of the frontier country, and later more rapidly as interest by Congress in river and harbor improvement gained in popularity; thus, the assignment of this increasing work to the Corps of Engineers.

The Mississippi River Commission was established by Act of Congress in 1878, and the California Debris Commission was established in 1893. The Board of Engineers for Rivers and Harbors was created by Act of 1902.

Many of these River and Harbor acts conferred additional duties upon the Secretary of War and the Chief of Engineers, such as: Issuing of permits and inspection of work affecting navigable waters, including the regulation of bridge-clearances, bridge-tolls, and use of drawbridges; the regulation and control of international waters; leases and licenses; establishment of harbor lines, sunken vessels, and wrecks; pollution of navigable waters; obstructions to navigation; and beach-erosion.

The Chief of Engineers, through the Board of Engineers for Rivers and Harbors, was charged by Congress in various acts to maintain records and statistics of the waterways and water-borne commerce of the United States, and to operate and maintain all improvements for navigation.

The Constitution of the United States provides for regulation of commerce. This led to acts of Congress for navigation improvements. Flood-control, formerly, was not expressly authorized, but navigation and flood-control were so closely related that flood-control soon became an important part of the early work of the Engineer Department. However, all work of that character was carried out under the authority of acts of Congress for navigation.

As previously stated, the first flood-control project was assigned to the Corps in 1910. This called for control of floods, removal of debris, and improvement of the Sacramento River, California. The next flood-control project was for the Mississippi River as authorized by Act of March 1, 1917, and enlarged or extended in scope in 1928. The 1927 Act and modifications in 1928 and 1935 provided for flood-control investigations on all navigable streams and their tributaries, except the Colorado River system. This assignment provides for continued investigations as the need arises, and to the end of the fiscal year 1937 over $11,600,000 had been appropriated for the work. Work accomplished to date thereunder has served as the basis for a large number of projects that have since been adopted by Congress.

The Act of June 22, 1936, called for an enlarged flood-control program of broadened scope. This act established for the first time in the history of the Federal Government a definite flood-control policy, which provides for participation by the Government in the construction of economically justified flood-control projects throughout the United States, in cooperation with the States, political subdivisions thereof, or other local authority.

It is of interest to note that while all River, Harbor and Flood-Control appropriations since 1824 have directed the Secretary of War, through the Chief of Engineers, to expend funds appropriated for flood-control purposes, the 1936 Act is the first Act of Congress which made River and Harbor and Flood-Control work a statutory function of the Corps.

The Act of June 22, 1936, provides that Federal investigations of watersheds and measures for runoff- and waterflow-retardation and soil-erosion prevention on watersheds shall be under the jurisdiction of and shall be prosecuted by the Department of Agriculture. The Act of August 28, 1937, clarifies the Act of June 22 by authorizing the Secretary of Agriculture to make preliminary examinations and surveys of all streams for which the Secretary of War has been directed to report upon for flood-control. It is thus seen that both the War Department and Department of Agriculture are required by Congress to prepare reports. The War Department is responsible for flood-control projects and the Department of Agriculture for watershed treatment and betterment. There is no conflict of interests or responsibilities as between the two departments, since the nature or character of work and investigations of the two departments are each highly specialized and different. The same is true as between these two departments and the work of the Bureau of Reclamation, which also is highly specialized and different. To be definite on this point I shall state that the Bureau of Reclamation is well equipped to handle all matters pertaining to control of water for reclamation-projects involving works for storage and distribution of water to land preparatory to irrigation; the Department of Agriculture, in its special field of soil-erosion, water-retardation, and soil-rehabilitation and reclamation, is well equipped to cope with such problems; and the War Department, by reason of long years of training, is likewise well equipped to handle the problems pertaining to flood-control and navigation. The foregoing is mentioned with the idea of dispelling any thought there may be as to duplication of effort as between the three departments. In recent years we have heard a great deal as to the possibility of duplication of effort by the several departments of the Federal Government, and in this connection, I should include the Weather Bureau, the Coast and Geodetic Survey, and the Geological Survey. Here are six branches of the Government, each of which is highly specialized in its particular field, but none is overlapping in its particular field. It is true that data collected by one department are useful to another department, but there are no instances wherein these departments actually duplicate the work of another department, even in the smallest detail of collecting stream-flow records and rainfall-gaging, or the survey of dam-sites, etc. The data of one department are available to all other departments and there is always a willing exchange of data when called for. I am sure that any of the departments which have just been mentioned, who desire cooperation with the Engineer Department, will be granted that courtesy to the fullest extent.

For years the Engineer Department, in carrying out investigations of navigation and flood-control projects called for by Congress, has made use of the facilities of a number of other Federal departments and bureaus, and similarly it has made its facilities available to the other departments, and has assured itself that its work is coordinated with the activities of the other branches of the Federal Government and with the agencies of State and local governments. For instance, the Biological Survey is always consulted where any waterway-improvements for navigation or flood-control planned by the Corps of Engineers are apt to touch upon its interests. Similarly, the Corps of Engineers is making use of the facilities of the Weather Bureau on an ever-increasing scale. This Bureau is aiding the Engineer Department in the establishment and maintenance of rain-gaging stations and in exhaustive studies of the maximum storms that may be expected over the various watersheds for which flood-control structures are being planned. Close cooperation is maintained with the Bureau of Reclamation in planning and constructing all water-conservation projects in the western part of the United States. All reports on preliminary examinations and surveys of streams in this area are furnished to the Bureau of Reclamation, and many of the reports involved contain joint recommendations of the two departments. The Geological Survey is at present engaged on an extensive program of stream-gaging, of snow-surveys, and of mapping for the Engineer Department. The interests of the National Park Service are involved in a number of navigation and flood-control projects planned and executed by the Corps of Engineers. Upon the request of the War Department, the Public Health Service has agreed to assist in eliminating the pollution of streams in the Ohio River Valley, and funds have been allotted by the War Department to the Public Health Service to cover the expenses of its part of the investigation. The Public Health Service has also cooperated with the Engineer Department in working out measures for the control of malaria and the elimination of mosquito-breeding areas wherever possible. The War Department uses continuously the facilities of the Department of Justice in land acquisition and of the Department of Labor in establishing minimum-wage rates, and in obtaining labor through the United States Employment Service. The Federal Power Commission has for many years referred to the War Department all applications for licenses for the development of hydro-electric power to determine the effect of the proposed works on navigation.

The Corps of Engineers has found it advantageous on many occasions to consult a large number of independent Government agencies having an interest in the works committed to this Department. To mention a few of these agencies, the recently created Civil Aeronautics Authority is interested in the plans being made by the Corps of Engineers for the provision of adequate seaplane anchorages and channels in many of the major harbors along our coasts. The Engineer Department is careful to keep the Bureau of Lighthouses advised of its plans for new facilities on our rivers and harbors, where the interests of the Bureau are affected in any way. Thus the Lighthouse Service is able to plan well in advance for additional aids to navigation that may be needed. The normal activities of the Engineer Department, in one way or another, frequently must be coordinated with the work of the Civilian Conservation Corps, the Inland Waterways Corporation, the Reconstruction Finance Corporation, Foreign Trade Zones Board, the United States Maritime Commission, and the National Youth Administration. Without exception, it has been found that wherever the interests of these various agencies touch those of the Engineer Department, pleasant relations have existed and the full measure of cooperation has without exception been attained.

The Public Works Administration and the Works Progress Administration have obtained from the Corps of Engineers technical assistance in the review of plans for works proposed by local interests to be prosecuted with funds provided by these administrations. In many cases, the field offices of the Engineer Department and individual members of the Corps of Engineers have been made available for the inspection of work undertaken with funds provided by the various emergency-relief acts. Today, all projects affecting the water-resources of the Nation and proposed for construction with Public Works Administration funds are referred to the Engineer Department for report as to whether the proposed.works conflict in any way with similar works being planned or built by this Department.

I have cited a few instances of the present excellent cooperation between the Engineer Department and a number of other Federal agencies. For several years, in the planning and execution of public works, the Engineer Department has profited by this cooperation. The cordial character of the cooperation between the various separate agencies of the Government is most gratifying and impressive.

There have never been any instances of lack of cooperation. Cooperation must be requested before it can be granted and, when requested, the nature of the request must fall within the purview of the law under which the two departments function. Obviously, funds appropriated for a specific purpose cannot be diverted to another purpose, even within one department, let alone to another department. When Congress directs an investigation which is the duty of one department to perform, that department cannot reassign, nor can any other department request that assignment be made to it. When an investigation and report are requested by Congress covering flood-control in any basin, the Engineer Department will investigate flood-control; this means all damage caused by floods and measures that are necessary to prevent dameging floods. Concurrently the Department of Agriculture will investigate runoff, waterflow-retardation, and soil-erosion problems within the same basins. Although Congress has recognized that the items which it has assigned to the Department of Agriculture are of great import and of national interest, there is nothing in the Act that would permit assignment of a flood-control problem to the Department of Agriculture for execution. However, such flooding as may occur from sheet-flow of storm-water, outside of well-defined channels, would be a proper subject for detailed investigation of the Department of Agriculture, and any investigation thereon, conducted by the Corps of Engineers, would be in the nature of correlating such sheet-flow with any general overflow of main streams located in the area. The preliminary reports of the two departments will cover the main subjects as assigned by Congress. The report of the Engineer Department will state that before complete protection from floods can be attained the problem of sheet-flow of storm-water into the damaged area will have to be solved, and that since this problem is closely related to soil-erosion, it is one that probably falls to the Department of Agriculture for consideration. It is thus apparent that even though soil-problems have, by Congressional Act, been tied to flood-control, there is no conflict of interests or overlapping of responsibilities between the two departments.

Under the conditions of local cooperation included in the Act of June 22, 1936, Federal funds appropriated for the execution of projects could not be applied to the cost of lands, easements, and rights-of-way necessary for the construction of a project, except when such costs exceed over 50 per cent of the total cost, and then only to meet one-half of the excess cost thereof. Also, that Act provided that a project could not be placed under way by the Federal Government until responsible interests had agreed to certain conditions of cooperation, as follows:

"States, political subdivisions thereof, or other responsible local agencies shall give assurances satisfactory to the Secretary of War that they will (a) provide without cost to the United States all lands, easements, and rights-of-way necessary for the construction of the project, except as otherwise provided herein; (b) hold and save the United States free from damages due to the construction works; (c) maintain and operate all the works after completion in accordance with regulations prescribed by the Secretary of War; . . ."

The Act of July 19, 1937, stated that "The Secretary of War is authorized to receive from States, and political subdivisions thereof, such funds as may be contributed by them to be expended in connection with funds appropriated by the United States for any authorized flood-control work whenever such work and expenditure may be considered by the Secretary of War, on recommendation of the Chief of Engineers, as advantageous in the public interest, and the plans for any reservoir project may, in the discretion of the Secretary of War, on recommendation of the Chief of Engineers, be modified to provide additional storage-capacity for domestic water-supply or other conservation storage, on condition that the cost of such increased storage-capacity is contributed by local agencies and that the local agencies agree to utilize such additional storage-capacity in a manner consistent with Federal uses and purposes: . . ."

The Act of June 28, 1938, modified the Act of June 22, 1936, and subsequent Acts. This modification enunciates a new policy regarding rights-of-way and lands, which is of such interest that I shall quote a portion thereof, as follows:

"Sec. 2. . . . That in case of any dam and reservoir project, or channel-improvement or channel-rectification project for flood-control herein authorized or heretofore authorized by the Act of June 22, 1936, as amended, and by the Act of May 15,1928, as amended by the Act of June 15, 1936, as amended, title to all lands, easements, and rights-of-way for such project shall be acquired by the United States or by States, political subdivisions thereof, or other responsible local agencies and conveyed to the United States, and provisions (a), (b), and (c) of section 3 of said Act of June 22, 1936, shall not apply thereto. Notwithstanding any restrictions, limitations, or requirements of prior consent provided by any other Act, the Secretary of War is hereby authorized and directed to acquire in the name of the United States title to all lands, easements, and rights-of-way necessary for any dam and reservoir project or channel-improvement or channel-rectification project for flood-control, with funds heretofore or hereafter appropriated or made available for such projects, and States, political subdivisions thereof, or other responsible local agencies, shall be granted and reimbursed, from such funds, sums equivalent to actual expenditures deemed reasonable by the Secretary of War and the Chief of Engineers and made by them in acquiring lands, easements, and rights-of-way for any dam and reservoir projects, or any channel-improvement or channel-rectification project for flood-control heretofore or herein authorized: Provided, That no reimbursement shall be made for any indirect or speculative damages: Provided further, That lands, easements and rights-of-way shall include lands on which dams, reservoirs, channel-improvements, and channel-rectifications are located; lands or flowage rights in reservoirs and highway, railway, and utility relocation."

It will be noted that provisions (a), (b), and (c) of the former Act are no longer applicable; provision (a) covers lands and easements; provision (b), damage claims; and provision (c), maintenance and operation. The status of provision (a), with regard to projects authorized in the 1938 and prior Flood-Control Acts, is fully covered in the Act which I have just quoted; but the status of the other two items, "damages," and "maintenance and operation," is the same as if no legislation had ever been enacted regarding them. This means that when a report is prepared, a recommendation will be made as to all items, (a), (b), and (c), so that Congress can decide what items of local cooperation will be required.

Section 3 of this Act provides for an important departure in previous procedure, as follows:

"Sec. 3. That in any case where the construction cost of levees or flood-walls included in any authorized project can be substantially reduced by the evacuation of a portion or all of the area proposed to be protected and by the elimination of that portion or all of the area from the protection to be afforded by the project, the Chief of Engineers may modify the plan of said project so as to eliminate said portion or all of the area: Provided, That a sum not substantially exceeding the amount thus saved in construction cost may be expended by the Chief of Engineers, or in his discretion may be transferred to any other appropriate Federal agency for expenditure, toward the evacuation of the locality eliminated from protection and the rehabilitation of the persons so evacuated: And provided further, That the Chief of Engineers may, if he so desires, enter into agreement with States, local agencies, or the individuals concerned for the accomplishment by them, of such evacuation and rehabilitation and for their reimbursement from said sum for expenditures actually incurred by them for this purpose."

The Flood-Control Act of June 22, 1936, and subsequent acts authorized projects in the Los Angeles District for flood-control of the Los Angeles County Drainage-Area amounting to a total of $70,000,000 and additional costs to local interests estimated at $5,000,000. The act of 1936 also called for preliminary examinations and surveys for flood-control on the Los Angeles and San Gabriel rivers and tributaries, which report is now nearing completion. The purpose of this report is to present to higher authority a full statement of flood-control needs for the entire Los Angeles and San Gabriel River Drainage-Basins with tentative plans, estimates, and economics thereof, in so far as the main drainage-areas, including tributaries, are a potential flood-menace. This report and another which is in course of preparation under the Act of June 28, 1938, calling for report pertaining to the Los Angeles County Drainage-Area, under the title "Streams in Los Angeles and Ventura counties, draining the Santa Monica Mountains, California, directly into the Pacific Ocean." will about complete investigations of all areas directly affecting Los Angeles proper.

The existing Los Angeles County Drainage-Area Flood-Control project units and their status as of November 1, 1938, are as follows:

| Name | Description |
|---|---|
| Compton Creek, Los Angeles River to Hooper Avenue | 6.3 miles of channel-improvements, 100 per cent completed. |
| Sycamore-Verdugo, to Upper Canada Bridge | 5.0 miles of channel-improvement, 100 per cent completed. |
| Alhambra Wash | 7.2 miles of channel-improvement, 100 per cent completed. |
| Ballona Creek (excepting capping jetties) | 9.0 miles of channel-improvement, 100 per cent completed. |
| Los Angeles River-Rio Hondo to Lankershim Boulevard | 23.8 miles of channel-improvement, 50 per cent completed. |
| San Gabriel River, Canyon to Sante Fe Reservoir | 3.5 miles of channel-improvement, construction not yet started. |
| San Gabriel River, Whittier Narrows Flood-Control Dam to Pacific Ocean | 21.6 miles of channel-improvement, construction not yet started. |
| Haines Canyon | 3.6 miles of channel-improvement, and large debris-basin, 100 per cent completed. |
| Hansen Flood-Control Dam on Tujunga Wash | 5 per cent completed. |
| Sepulveda Flood-Control Dam on upper Los Angeles River | Construction not yet started. |
| Santa Fe Flood-Control Dam on San Gabriel River | Construction not yet started. |
| Whittier Narrows Flood-Control Dam on San Gabriel River | Construction not yet started. |

The entire project is 25 per cent completed. This 25 per cent completion refers to work under the $70,000,000 project. Therefore, for a complete understanding of the flood-control work in the Los Angeles Area it can be stated that a large amount of flood-control work, involving construction of concrete-lined channels and debris-basins, was completed during 1936 and 1937 as emergency projects for unemployment relief.

The total expenditure of funds to November 1, 1938, for the flood-control work under the Los Angeles project amounts to $24,393,084.69. Of this amount $12,547,881.22 was from regular funds and $10,963,311.33 from ERA funds, making a total of $23,511,192.55 from Federal funds and $881.892.14 from contributed funds. The foregoing figures are construction costs during fiscal years 1938 and 1939 applicable to the adopted project. During the fiscal years 1936 and 1937, $10,134,823.86 and $10,170,822.66, respectively, were expended on emergency relief flood-control projects. The total expenditure for the three and one-half years was $45,486,679.21. This figure includes about $800,000 for emergency relief project work, during the fiscal years 1938 and 1939, not previously given. As of October 31, 1938, the unexpended funds remaining for work until June 30, 1939, obligated and unobligated, amount to $5,374,929.52, of which more than three-fourths is obligated. During the fiscal year 1937 there was expended throughout the United States $55,000,000 for flood-control, of which $11,000,000, or one-fifth, was expended in Los Angeles. I am sorry that comparable figures are not available for subsequent years.

It is probably a matter of general public interest to know that there are two distinct classes of reports on flood-control (also Rivers and Harbors). They are (a) preliminary-examination reports and (b) survey reports. The preliminary-examination reports are first made in order to determine whether a survey is warranted. A flood-control survey and report usually costs about 20 to 40 times as much as a preliminary-examination report, so it is very important to know in advance whether such large expenditures are justified. Hence, a careful general economic study of the improvements desired by local interests is made for the preliminary-examination reports. The survey reports are based upon detailed accurate field-surveys, including an extensive economic survey.

Federal responsibility of the Corps of Engineers, as you may have gathered from the references previously made to various acts, includes only the carrying out of the mandates of Congress, as directed by specific acts of Congress. The Corps cannot initiate projects. This must be done by local interests. When local interests feel that they have a project which falls within the scope of the existing law, they can obtain consideration of it by having their Congressman include it in the next Congressional bill. A stream which is to receive consideration for flood-control, when included in an act, is referred to the District Engineer for report, as previously indicated. Reports are forwarded to the Chief of Engineers through the Division Engineer, who reviews them and makes comments thereon with recommendation for or against a survey. The Chief of Engineers forwards the report with remarks and recommendations of the Division Engineer to the Board of Engineers for Rivers and Harbors. This Board, with its staff of engineers, makes a study of the project and recommends that a survey be made or that a survey be not made, and when a survey is not recommended the preliminary report, with the action of the Division Engineer and the Board of Engineers thereon, is forwarded to the Secretary of War by the Chief of Engineers with his report. The Secretary of War forwards the report with action taken thereon by the Division Engineer, Board of Engineers, and the Chief of Engineers, to the Flood-Control Committee of Congress.

If a report to Congress, submitted by the Chief of Engineers through the Secretary of War, is favorable to improvement, usually Congress authorizes a project in accordance therewith. When a project is adopted and funds therefor have been provided, the Corps of Engineers, through the appropriate division and district engineers, prepares detailed or official plans and executes the project accordingly.

Just because a preliminary examination is favorable does not always signify that the survey report will be favorable to improvement. However, usually the preliminary examinations are in close general agreement with the surveys in so far as economic justification is concerned, but a survey report will determine more accurately the cost of adequate improvements. This cost may therefore change the relative economics of a project, thus making it more or less justified than stated in the preliminary examination report.

When reports are unfavorable, interested parties are notified in writing by the Division Engineer and are given an opportunity to present, before the Board of Engineers for Rivers and Harbors, an appeal from the findings of the Division Engineer. If the appeal presents new or additional data or facts, and the facts so warrant, the Board of Engineers will return the report to the Division Engineer for review and a supplemental report.

I might add, in closing, that the Corps of Engineers cooperates fully with local interests, and all Federal agencies and bureaus, in the preparation of reports; individual, city, county and state engineers are consulted and are given full opportunity to express their views, etc. These views are often of great assistance.

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CHAIRMAN MORRIS--You have heard this very interesting presentation of the Act and the work of the Army Engineers in flood-control matters. I think this is, perhaps, the best brief summary of their activities in this field that I have heard, Captain Withers. This field has been so tremendously broadened since the adoption of this Amendment in 1938 which includes railway land and rights-of-way. It seems almost that the door has been opened too wide with expenditures by the United States and the only restriction there is is the efficiency of the Engineer Corps in working out these problems and determining what should be done.

## THE NATIONAL FLOOD-CONTROL PROGRAM IN THE UNITED STATES DEPARTMENT OF AGRICULTURE

Harry E. Reddick

Floods have been with us since the dawn of history. Early records describe not only the destruction caused by floods, but also Man's ineffectual efforts to prevent great losses of life and property once the raging waters were upon him. While no one can deny the value of well-conceived construction programs designed to protect property and lives from floods, it is important to realize that modern scientific research has clarified the contributing causes and encouraged us to take them into consideration.

Accepting the definition of a watershed as including all land from which runoff-waters flow into a common outlet, we immediately see that a watershed may include many different types of terrain and vegetation ranging from heavily timbered and precipitous slopes on the upper edges of the watershed through the brushy foothills and the intensely cultivated lower-lying fields to the flood-plain areas where the river converges with a larger one or enters the ocean.

To combat floods successfully over such a wide and varying expanse must necessarily involve a number of separate techniques closely coordinated in a single over-all program. The United States Forest Service with its years of experience has developed successful methods for the retardation of runoff in the upper forested areas that are largely composed of publicly-owned land. On the agricultural lands and the foothill areas, the Soil Conservation Service has developed methods that are the result of many years of experimentation under varying conditions all over the country. These methods accomplish retardation of runoff and conservation of soil and water by means of proven devices and practices.

On the lower portions of the watersheds, where the prevention of damage to urban and valuable suburban property is a major problem, the Army Engineers with their debris-basins, high-velocity channels, and other methods have a very important place in the picture. Thus, it is seen that flood-control on a watershed-basis involves more than one technique, and to be successful must include the efforts of more than one agency.

The present program is a culmination of 30 years of effort initiated in Congress in 1907 by the late Senator Francis G. Newlands. With prophetic vision, he maintained at that time that flood-control was a national problem and demanded treatment of the entire watershed, including scientific soil-cultivation, in such a way as to absorb instead of shed the rainfall.

I will not discuss the historic details any further, except to point out that the culmination of this far-sighted effort by Senator Newlands has resulted in the so-called Omnibus Flood-Control Act of June 22, 1936. This Act for the first time established a comprehensive flood-control program for the entire country and is the enabling legislation under which the present program of the Department of Agriculture is organized.

The responsibility of the Department of Agriculture in connection with nation-wide flood-control can best be stated by quoting from the Act itself as follows: "The Federal Government should improve or participate in the improvement of navigable waters or their tributaries including watersheds thereof," and in an amendment, the Act further states that "the Secretary of Agriculture is hereby authorized and directed to cause preliminary examinations and surveys to be made of runoff and waterflow-retardation and soil-erosion prevention on the watersheds."

Under the new program the Department operates by three successive steps which can be described briefly as follows: The first step is a preliminary examination of a watershed made rather quickly but with sufficient care to determine within reasonable limits whether or not the flood-problem is of such magnitude and character as to warrant detailed study.

The second step is a so-called detailed survey which calls for the careful study of the watershed and its problems and which results in the formulation of a general action program for the protection and improvement of the watershed, together with an estimate of cost so that, if Congress so desires, it may make an appropriation to enable such a program to be undertaken. The technical studies required in connection with the preliminary examination and the detail survey are handled by the Forest Service and the Soil Conservation Service. The Bureau of Agricultural Economics joins with these two services for the purpose of evaluating the programs which they recommend on the basis of the economic justification for an action program. This, of course, is a very important part of the field-study since the law requires that benefits obtained must justify the expense involved.

The third step is the action- or work-program which can be initiated only after Congress has appropriated funds for the project. The work-program involves a very careful study of all portions of the watershed and the development of complete farm or area work-plans so that a well-balanced program of construction and improvement may be consummated.

By administrative arrangements which need not be detailed at the present moment, overlapping of effort by the Forest Service, the Soil Conservation Service, and the Bureau of Agricultural Economics is eliminated and unified leadership is provided in each watershed worked on. Thus the Department of Agriculture, even though working through three agencies, approaches the problem of flood-control from a departmental standpoint rather than from the standpoint of any one technical bureau.

It should be pointed out, however, that while the Department of Agriculture has, through the work of its separate bureaus, ample technical and operating experience with the various phases of flood-control, this is its first opportunity to combine them in a complete program of protection and improvement on large watersheds.

The Soil Conservation Service deals only with the agricultural land, and in order that a complete picture of the Department of Agriculture's work in flood-control be given, it will be necessary to describe briefly the work of the Forest Service as well. There is no definite allocation of areas for survey on the basis of mountain versus valley, but, as a general thing, the Forest Service accepts responsibility for the forest and brush land and the Soil Conservation Service accepts responsibility for the study of agricultural and range land.

The most important task facing the Forest Service is the protection of vegetation and the protective mantle of litter on the mountain-areas, because the vegetation and the protective cover serve the triple purpose of increasing infiltration, reducing and slowing up runoff, and very largely eliminating movement of soil and debris. Consequently, the Forest Service plans to protect the vegetative cover, and to restore it wherever it has been removed, whether by fire or other forms of misuse and mistreatment.

Accordingly, perhaps the most important work of the Forest Service will be to develop improved fire-protection. This will require the construction of fire-breaks, generally constructed along the summit of the ridges, and of motorways, which are narrow roads to permit passage of trucks carrying equipment and water. It will also require the construction of lookouts, telephone lines, and all of the numerous other items necessary for dependable control of forest-fires as well as adequate personnel.

In addition to protection of vegetation over the upper watershed as a whole, the Forest Service will give special attention to areas where slips have occurred, where highways have exposed deep cuts or created unprotected fills, and to areas which for some other reason have lost their normal protective cover. Accordingly, it is expected that the Forest Service will do a certain amount of reseeding, revegetating, tree-planting, and also a certain amount of specialized construction work, such as wattling of exposed slopes.

Another important aspect of the work of the Forest Service will be the use of such minor construction work as channel-sills, debris-barriers, and other protective and control-structures to protect the channels and retain material washed down from the hillside in order that it will not enter the debris-basins below. When consideration is given to the vast mountain-areas involved and their potential production of debris and rubbish, it is easy to understand the very great value of these measures as protection to the extremely expensive flood-control structures which are necessary in the lower reaches of the river and on the lower flood-plain.

The work of the Soil Conservation Service is similar in its objectives but employs the technique of soil-conservation rather than that of forestry for the reason that its responsibility is for the agricultural lands which lie mostly in the valley- and foothill-areas.

The Soil Conservation Service has two basic objectives in its flood-control work. The first is to reduce runoff and soil-loss by means of changes in land-use and the installation of control-structures. The second is to provide safe passage of flood-waters over or around agricultural lands by means of suitably protected channels.

In some areas a great deal of study has been given by local agencies to the establishment of a local flood-control program. In some cases, this local study has been applied only to the concentrated stream-flows but in others, as in the Los Angeles Basin, considerable study has also been given to the agricultural and upland areas. Obviously, the Department of Agriculture must give consideration to these plans, cooperate with the local agencies, and develop the most satisfactory over-all program making the best possible use of control measures and practices already in operation.

The agricultural land-areas can be roughly divided into foothill-lands and valley-lands. Speaking in general terms, the foothill-lands are devoted to hay and grain, to pasture, to grazing, and to brush and woodland; whereas the valley-lands ordinarily are devoted to more intensive agriculture, including orchards, truck-crops, and, to some extent, grain.

Very frequently, the foothill-lands present the most difficult problem for two reasons. In the first place, the technical principles to be applied in the protection of such land, which is frequently semiarid and difficult to vegetate, have not been worked out to the same degree of demonstrated efficiency as have the technical procedures for the more intensively cultivated valley-lands. Furthermore, the very low value per acre of the hill-lands makes it difficult to persuade private owners to adopt the necessary and relatively expensive control-measures required.

In general, however, it is intended either to restore upland-areas to natural watershed-conditions or, as in the case of the badly overgrazed uplands of Southern California, to institute some type of use-control. In addition, where conditions permit and justify, it is probable that contour-ditches or contour-furrows may be used in order to increase infiltration, and thus build up the water-supply which in turn will improve the vegetation, and to eliminate or materially slow up the runoff and the consequent severe sheet-erosion.

In the smaller waterways, it will be necessary to do at least two things. The first is to provide appropriate bank-protection, usually vegetative, at points where severe cutting is occurring. The second is to place at the proper points in the stream-beds, construction work such as soil-conserving dams to catch and retain debris so that it may not pass on downstream and increase the already serious problem of maintaining unimpaired the capacity of reservoirs and the effectiveness of debris- and silting-basins.

Another item which can perhaps be worked out effectively is the use of vegetative material in the smaller stream-beds to catch and retain silt and debris in order to reduce the amount of material to be handled by the soil-saving dams below. In addition, it will be necessary for the Soil Conservation Service to do a certain amount of specialized work, such as revegetation, seeding of bare spots, revegetation of slips, and the protection of highway cuts and fills.

On the lowlands the program will consist almost entirely of two principal parts. The first item will be the construction of channels with either vegetative or masonry banks to carry accumulated flood-waters over and past valuable cultivated lands. In many cases, streams of this character are meandering in a serious and unpredictable manner, causing the loss of many acres of very valuable cultivated land.

Many instances exist where, through lack of coordinated effort, ranchers and property owners have installed flood-protection devices of one kind or another, the ultimate effect of which is to protect the owner's property at the expense of others or of the community as, for example, in connection with the flooding of roads. A coordinated program will correct this and may in some instances accomplish a thoroughly satisfactory control of such waters at less total cost than will be represented by the uncoordinated efforts of the individual owners.

The second general type of control required on the valley agricultural lands is perhaps the more important and consists of such changes as will cause greater infiltration, less runoff, and less erosion. This is extremely important because the cultivated areas are extensive, they are constantly stirred up by cultivation, and, unless properly protected, they lose enormous amounts of silt which go downstream only to fill up flood-control reservoirs, settle out at critical points in flood-control channels, or perhaps spread in the form of harmful deposition over the areas lower down.

The erosion-control practices appropriate for cultivated land have been worked out in complete detail and their effectiveness has been amply demonstrated. These measures are simple, easily understood, and on the whole not expensive to install. Furthermore, in general, they do not involve any maintenance expense.

Among the measures referred to are the turning of cultivation on moderate slopes from uphill and downhill direction to crosswise direction on lines approximating contours. In a similar manner, irrigation furrows can also be placed on grade contour-lines. These two measures alone, in many instances, will give adequate protection to the area involved, resulting in greatly increased infiltration and greatly decreased runoff and erosion.

Where the slopes, soil, and other conditions are appropriate, basin-listing is recommended. At other points and on other areas terraces, annual ditches, contour-ridges, etc., are recommended and are all designed to retard runoff, increase infiltration, and reduce erosion.

Vegetative controls will also play a definite part in our work. These include, for example, the application of a cover-crop, either permanent or annual, in order that the soil may have a protective covering during the winter storms. Crop-rotation and other methods designed to improve the texture of the soil are also very helpful because they keep the soil in such condition that it is highly absorptive and able to take up a very large percentage of the rainfall.

A point of very great importance in many areas, such as Southern California, is the replenishment of underground reservoirs, and, accordingly, the nature and extent of underground reservoirs are important factors in the study of the watershed. Every acre-foot of water which can be induced to sink into the soil and eventually contribute to the ground-water reservoir represents actual cash value to the community, and, in some cases, the successful maintenance of a satisfactory ground-water reservoir may mean the difference between prosperity and poverty for the community.

One of the important problems is the question of how the Soil Conservation Service is to accomplish land-use changes on private land which may, in some cases, radically affect the use to which the owner is putting his property and which may also affect income on that property. It is probable that such changes can be brought about only through the process of educating private owners and converting them to the acceptance of these changes. This will require that the actual flood-control program be planned on a long-time basis that will allow for the inherent slowness of the necessary educational work.

In general, it is anticipated that soil-conservation districts will be formed covering any watersheds forwhich appropriations may be made. These soil-conservation districts will be the legal agency through which the Soil Conservation Service and, in some cases, the Forest Service will deal with individual owners. The appropriation will probably be expended under the direct supervision and control of the appropriate Federal agency, but the directors of the district will play a most important part because it is through them that cooperation with and by private property owners can be obtained and the security of works and measures made certain.

It is essential that there be developed a community appreciation of the fact that the watershed is a unit and that the cause of damage on a certain area may originate at a point several miles away. Consequently, it is probably going to be necessary to work up some legal mechanism whereby the community may take a watershed-viewpoint and apply corrective measures at the source of the trouble.

Perhaps, in such cases, it may become necessary for the community to bear a portion of the expense through some procedure not yet developed, and it may be necessary for the community to adopt and maintain some type of land-use regulations in order that areas which constitute a hazard may not be handled under the system of individual ownership in such a manner as to seriously depreciate community interest in the area as a whole.

In examining the problems and suggested methods of control, we have uncovered certain social and economic problems peculiar to and a definite part of any program which includes large areas, parts of which are owned by numbers of people. There is as yet no practical formula for bringing about a unanimity of opinion or concerted action by land-holding groups even in a cause such as flood-control. Undoubtedly, long and patient education as well as further research will be required before we can successfully solve the problem cf upstream flood-control on a nationwide scale.

Soil Conservation Service,
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## FLOOD-CONTROL IN CALIFORNIA

Edward Hyatt

The State of California has a recognized interest in flood-control of long standing. Through legislation, investigations and planning, and direct expenditure of State funds, it has actively assisted or participated in flood-control since the Fifties.

One of the most serious problems early confronting the pioneers who settled in the Sacramento and San Joaquin valleys, as well as in other sections of the State, was that of controlling floods. Far too commonly towns and agricultural lands bordering the streams were inundated by floods resulting in destruction of life and property. Individuals who sought to cope with the problem soon found it to be far beyond their ability and resources and it was realized that only by organized effort could the necessary resources be mustered to provide the protective works required. It was natural that these early pioneers should turn to the State for assistance.

In 1850 the United States Congress adopted the so-called "Arkansas Act" providing for Federal grant of swamp and overflow lands to the States and placing the obligation on the States to utilize funds obtained from the sale of those lands for their reclamation. Beginning in 1855, legislation was enacted by the State Legislature culminating in 1861 with the passage of the Swamp-Land Act which provided for the State assuming the responsibility for the reclamation of the swamp and overflow lands and creating a board of swamp-land commissioners. The Act provided for the sale of these lands by the State to individuals who would undertake to reclaim them. It also authorized the formation of swamp-land or reclamation districts to carry out projects for flood-control and reclamation.

Although this legislation was modified by subsequent enactments of the Legislature, it furnished the necessary organizational and financial procedure for carrying out flood-control and reclamation works on a large scale throughout the State. It marked the beginning of flood-control and reclamation developments in the State which have resulted in providing substantial protection from floods on over a million acres of lands subject to inundation in the Sacramento and San Joaquin valleys alone. Later, the procedure for organization of reclamation districts was transferred from the State to the counties and many reclamation districts were organized under county supervision. However, flood-control and reclamation districts have been and still can be organized by special State legislation.

The problems of flood-control along Sacramento River and its tributaries were greatly augmented following the advent of hydraulic mining in 1856. As a result of these operations, debris was dumped into the streams and gradually filled up the channels along the valley-sections, raising the flood-plane, inundating lands not previously flooded, and overtopping levees already constructed. Although hydraulic mining was stopped by injunction in 1884. the problems arising from the debris filling the channels continued for many years thereafter.

Here again the State took a hand in the solution of these problems. The State Legislature directed investigations to be made to determine remedial measures. Largely due to the urgent endeavors of State officials, the Federal Government took an interest in the problem and in 1893 Congress passed the California Debris Commission Act creating a commission charged with the duty "to mature and adopt plans for the purpose of improving the navigability, deepening the channels and protecting the banks of the rivers, and affording relief from flood-damages." At the same time, the State Legislature passed legislation providing for cooperation between the State and the Federal governments in the construction of works for the restraining and control of the mining debris. The State appropriated $250,000 in 1897 to bear half the cost of the work and an additional $150,000 was appropriated therefor in 1901.

With the passage of the California Debris Commission Act, and the creation of the debris commission, provision was made for the initiation of studies and investigations which finally led to the formulation of plans and the construction of one of the largest single flood-control projects in the State, namely, the Sacramento Flood-Control Project. The plans adopted for the project were submitted in a report to Congress in 1910. Prior to this time a minor project had been authorized by Congress and construction started with funds furnished in equal amounts by the State and the Federal Government. The major project was not authorized by Congress until 1917 although it had been definitely adopted by act of the State Legislature in 1911. Work on the major project proceeded after the congressional authorization in 1917 which provided for the State and local landowners assuming about five-sixths of the total construction cost then estimated at $33,000,000. In 1928, Congress modified the terms of financing, providing for the Federal Government assuming one-third of the cost and the remaining two-thirds divided equally between the State and the local landowners benefited. At the same time the estimated cost of the project was increased to about $51,000,000. The obligation assumed by the State in this project will amount to $17,600,000, when completed.

In addition to financing a third of the cost of the Sacramento Flood-Control Project, the State Legislature enacted legislation in 1911 creating the State Reclamation Board with the duty of passing upon and approving plans of reclamation related to the project. In addition, the Legislature in 1913 created the Sacramento and San Joaquin Drainage-District, vested its management and control in the reclamation board, and provided machinery for the assessment of the lands benefited by the project to obtain the portion of the total cost for which the landowners were obligated under the Federal and State legislation.

State financing of flood-control works has not been confined to the Sacramento Flood-Control Project. The State also has assisted in the financing of the Los Angeles County Flood-Control Project with funds appropriated therefor, amounting to four and a half million dollars. The Legislature appropriated $400,000 in 1931 to assist in the construction of flood-control and related conservation-works in San Bernardino County. In addition there have been special appropriations made for miscellaneous works of flood-control in many sections of the State.

Although flood-control and reclamation works constructed by reclamation districts organized under State law have been chiefly financed by the local landowners within their borders, a substantial amount of State funds has been spent for this work. In 1866, when the obligation of swamp-land reclamation was turned over to the counties, the State also turned over all the moneys that had accrued from the sale of the swamp and overflow lands and these funds were subsequently used for the construction of protective levees and accessory works. In accordance with a report by the Commissioner of Public Works submitted to the Legislature in 1894, State funds in the amount of over $3,000,000 had been expended up to that date in connection with the flood-control works. In addition, starting with an appropriation of $300,000 in 1897, the State has appropriated between two and three million dollars for the improvement and rectification of river-channels throughout the State which to a large extent have been an aid to flood-control. The State also is obligated to maintain and operate certain completed portions of the Sacramento Flood-Control Project and funds are provided by the Legislature to defray the cost of such maintenance and operation.

In the field of investigations and planning for flood-control the State has been active since the passage of the original swamp-land reclamation legislation. The first legislation directing an investigation for the purpose of formulating plans of flood-control was enacted in 1878, which also created for the first time the office of State Engineer. Mr. William Ham Hall who served as the first State Engineer, presented a report to the Legislature in 1880 in which he recommended works for the control of mining debris, and that the construction of levees be systematized and placed under the control of the State. Subsequently, the State participated in formulating the plans for the Sacramento Flood-Control Project. The general plan adopted for the project was originally outlined by a State Commission of Engineers. The State also formulated preliminary plans for flood-control on the San Joaquin River and its tributaries which, however, were never adopted or carried out.

In 1921 the Legislature enacted legislation providing for the so-called "water-resources investigations" which were carried on continuously for over ten years thereafter with an expenditure of over $1,000,000 therefor. The general policy and scope of these investigations are best set forth by the Act itself (Chapter 889, Statutes of 1921) which is quoted in part as follows:

"Sec. 1. It is hereby declared that the people of the State of California have a paramount interest in the use of all the waters of the State and that the State of California shall determine what waters of the State, surface and underground, can be converted to public use, or controlled for public protection.

"Sec. 2. The State Engineering Department is hereby authorized and instructed to make the investigations in this act provided for and for the purposes herein specified.

"Sec. 3. It shall be the duty of the State Engineering Department to determine the maximum amount of water which can be delivered to the maximum area of land, the maximum control of flood-waters, the maximum storage of waters, the effects of deforestation and all possible and practicable uses for such waters in the State of California.

"Sec. 4. It shall be the duty of the State Engineering Department to determine a comprehensive plan for the accomplishment of the maximum conservation, control, storage, distribution, and application of all the waters of the State, and to estimate the cost of constructing dams, canals, reservoirs, or other works necessary in carrying out this plan, and to report the result of such investigations with recommendations not later than the legislative session of 1923."

This legislation authorizes and directs comprehensive investigations and studies for the formulation of plans to effect the maximum practicable conservation, regulation, utilization, and distribution of State's water-resources. It is desired to point out in particular that the investigations and planning as authorized, include as one of the specific features thereof maximum control of flood-waters and the consideration of the effects of deforestation.

An important part of these investigations and the plans formulated as a result thereof pertain directly to flood-control. One of the major technical studies carried out relates to the control of floods by reservoirs on which a special report was issued. As a result of these special studies the practicability of the utilization of major surface storage-reservoirs for the dual purpose of conservation and flood-control was demonstrated. In the report on the State Water Plan submitted to the Legislature in 1931, provision has been made in the plans, when practicable, for flood-control as a definite feature of the major surface storage-reservoirs proposed. Flood-control is considered as one of the major objectives of the State Water Plan. The initial unit of this plan--the Central Valley Project--contemplates flood-control regulation in both the Shasta and Friant reservoirs.

The foregoing historical account of the State's activities in matters of flood-control reflects what the position of the State has been in regard to flood-control up to recent years. It is evident that flood-control has been recognized as an interest of the State; that the State has actively assisted or participated in the planning, construction, operation, and maintenance of flood-control works; that it has cooperated with both local interests and with the Federal Government in flood-control projects; and, lastly, has appropriated funds in substantial amount for flood-control purposes.

What is the State's position in regard to flood-control now, and what will it be in the future? The answer to both these questions is to a large extent governed by the policies and procedure of the Federal Government with respect to flood-control, which in recent years have been undergoing substantial change.

Up to 1936 it was generally considered that the Federal Government had no general flood-control policy. However, flood-control as a function of the Federal Government had been at least partially if not wholly recognized, particularly on the Mississippi River and to some extent on the Sacramento River in California, by the passage of the Mississippi Flood-Control Act in 1917, and more particularly by the Mississippi Flood-Control Act of 1928. In the latter Act, provision was made for the first time for the entire cost of construction of flood-control works on the Mississippi River to be paid for by the Federal Government without local contribution.

The Flood-Control Act of 1936, however, set a new and far-reaching policy with respect to the Federal interest in flood-control. It declared that flood-control was a proper activity of the Federal Government in the interests of the general welfare if the benefits are in excess of the cost. It provided for the entire construction cost to be paid out of Federal funds but required local participation in furnishing rights-of-way, saving the United States free from damages, and in assuming the obligation of maintaining and operating the works after completion.

This Act was amended at both the 1937 and 1938 sessions of Congress. The amendments passed by the 1938 Flood-Control Act are radical in nature. The three conditions in the 1936 Act pertaining to local participation were eliminated. The legislation, as it now stands, provides for the construction of flood-control projects entirely at the expense of the United States including necessary rights-of-way and properties; and presumably for the operation and maintenance of "any dam and reservoir project, or channel-improvement or rectification project." The legislation as amended also provides for reimbursement to local agencies for expenditures made by them heretofore for lands, easements, and rights-of-way on authorized projects.

This Federal flood-control legislation as amended up to 1938 authorizes an expenditure of $375,000,000 for carrying out specifically authorized flood-control projects over a five-year period ending June 30, 1944. It also authorizes and directs preliminary examinations and surveys for flood-control and allied purposes on rivers and other waterways by the United States War Department, and investigations of watersheds and measures for runoff and water-flow retardation and soil-erosion prevention on watersheds by the Department of Agriculture, and authorizes funds for such investigations. In California, investigations have been authorized and directed on practically every important stream in the State. These are being actively prosecuted by both the United States Army Engineers and the Department of Agriculture and considerable progress has already been made.

Since the advent of these new Federal policies with respect to flood-control and the initiation of flood-control investigations and planning by the United States Army Engineers and the United States Department of Agriculture for flood-control in California, the State has entered upon a program of cooperation with both of these Federal departments. This program, agreed upon after over a year's consideration and negotiations under the leadership of the State Planning Board assisted by other State agencies, provides the following:

(1) State to advise on extent of investigations and surveys and the chronological order of their undertaking.
(2) Data and information to be interchanged.
(3) State to collect and make available additional data desired by departments.
(4) Representative of State to attend all hearings and participate therein.
(5) State to review all data collected, advise and confer on studies and preparation of reports, review reports, and submit comments and recommendations with respect thereto.
(6) Efforts of two agencies to be coordinated.
(7) State may undertake independent investigations on streams not now authorized.

Actually this program of cooperation was started prior to the consummation of these agreements. The cooperation on the part of the State is being handled by the Division of Water Resources of the Department of Public Works, with the College of Agriculture of the University of California collaborating on the investigations of the Department of Agriculture. The State has been keeping in close touch with the investigations which the two Federal departments have under way. All hearings have been attended by a representative of the State and the investigations and reports have been reviewed.

By means of the cooperative procedure that has been arranged, the State has been and will continue to assist these Federal departments by supplying all available basic data and the results of the hearings of investigations and studies which the State has made. It will, to some extent, it is hoped, have some part in the final formulation of plans for flood-control.

The State is also cooperating with the United States Geological Survey and providing funds for investigations and studies and preparation of reports on the floods of the 1937-38 season. These reports will be similar to others prepared by the United States Geological Survey on streams in other sections of the Nation and will relate to the December 1937 flood in Northern California, and the March 1938 flood in Southern California.

One of the most important activities of the State, evidencing its present position in regard to flood-control, is the work now under way on the repair and rehabilitation of flood-damages from last year's floods. During last season flood-damages were suffered in practically every section of the State. Following the December flood in Northern California the Legislature appropriated $150,000 for the repair of levees along the Sacramento River and its tributaries, particularly in the counties of Glenn, Tehama, Butte and Shasta. After the March 1938 flood the Legislature at a special session appropriated emergency funds in the amount of $5,000,000 to carry out repair and rehabilitation work. These funds have been made available to public agencies upon application to the Governor and the Director of Finance. Practically the entire appropriation has now been allocated with nearly every county in the State sharing. Allocations have been made only after careful examination and reports, and after approval of plans and specifications. Disbursement of funds has been made upon approval of statements of actual expenditures made. The procedure has involved the preparation of over 250 engineering reports and over 150 contracts with various public agencies.

As to the future position of the State in regard to flood-control, it is evident that this will depend to a large extent on the policies and procedure with respect to flood-control carried out by the Federal Government. The State's position and policy will have to be adjusted to meet the operations of the Federal Government.

From the standpoint of the State the 1938 Flood-Control Act is objectionable in several particulars, both as to what it contains and as to what it does not contain. Local participation is eliminated, hence there is no local yardstick of need. The act is silent as to operation and maintenance of projects after completion. It is assumed that they will be operated and maintained by the United States. In various places the Act needs interpretation. For example, what projects are eligible for reimbursement of certain past expenditures under the definition "channel-improvement or channel-rectification projects"?

Another objection to this Act from the standpoint of the State is the lack of recognition of State water laws and of protection to water rights acquired under State laws. Nowhere in the Act is there any reassurance that water rights acquired under State laws will be respected, or that State laws will be followed in acquiring any water rights which may be necessary for the project. These points are all clearly covered in the Reclamation Act.

Another point to consider is that while the Act directs investigation for "flood-control and allied purposes," in the absence of more specific language in the law relating to conservation it cannot be certain that the investigations of the Federal departments and the projects which will result therefrom will give sufficient consideration to the needs for conservation in connection with flood-control works. Admittedly flood-control must be the primary purpose of any works constructed under this Act. However, in the West where use of the water itself is all-important, all flood-control reservoirs should be constructed and operated to afford the most beneficial and economic use of water stored in such reservoirs consistent with the primary use. The paramount importance of water-conservation in California is universally recognized and plans formulated for flood-control should provide for the maximum practicable water conservation in conjunction therewith.

It is desired to make it clear that the foregoing discussion with respect to Federal flood-control policy implies no criticism of local officers or administrative officials of the Departments of War and Agriculture. It is the Congressional policies established by the 1938 Act that are considered unsatisfactory from the standpoint of the State. It is believed that the best interests of all would be served if the 1938 Flood-Control Act were clarified.

There is a growing demand throughout the State for adoption of a flood-control policy and the provision of funds by the State for flood-control. Legislation was introduced but not approved at the last session of the Legislature directed to the creation of a State flood-control board to govern all flood-control investigations and activities of the State. As previously stated, the consideration and adoption of a definite policy and procedure by the State with respect to flood-control must of necessity depend to a large extent upon present and possible future policies and activities of the Federal Government.

No State flood-control policy has been declared since Federal flood-control policies were so radically changed in recent years. The nearest approach to a general State policy, as far as legislation is concerned, is believed to be set forth in the act passed by the Legislature in 1921, the provisions of which have already been quoted in part. This policy generally stated is that flood-control is a major problem in which the State has a direct interest and obligation; that in so far as practicable the maximum extent of flood-protection should be obtained by regulation and control; that flood-control must be considered as one feature of the more comprehensive problem of water conservation and regulation; and that remedial measures for flood-control should be planned in so far as practicable so as to effect the maximum conservation and utilization of the available water-resources.

State Engineer,
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## INTRODUCTION

Dinner was held December 16, 1938, at Mrs. Gray's Inn at Westwood Village, after which the papers were read and the business on hand was discussed. James E. Jones, Local Chairman, presided.

The following 25 persons attended the meeting.

L. E. Blakely
J. E. Church
F. R. Cline
Ashton R. Codd
Phillip S. Cowgill
Carl Elges
R. D. Goodridge
James E. Jones
William A. Lang
Finley B. Laverty
George A. Lewis
Pete J. Maga
James C. Marr
Ross W. Mathews
Otto H. Meyer
Fred H. Paget
Beermaun Paul
Wayne Paulsen
J. E. Phillips
J. J. Prendergast
Fred D. Pyle
Jesse C. Wanslee
R. D. Waterhouse
Walter J. Wood
R. C. Youngquist

J. E. PHILLIPS made a statement relative to the value of cooperative snow-surveys, the benefits derived by an informal meeting of this type, and also stated the value of forecast in the economical distribution and handling of a water-supply system for either a small or large city. Tribute was paid to Dr. J. E. Church as a pioneer in this snow-survey work.

## SNOW-SURVEYING

### STATUS OF PROPOSED BULLETIN ON PRINCIPLES AND PRACTICE OF SNOW-SURVEYING

James C. Marr

Early in 1935 the National Resources Board, Water-Resources Section, issued "Preliminary statements and specifications for hydrologic data" [Mimeographed report, Form No. 100348, by Donald M. Baker, H. K. Barrows, J. P. Dean, Willis R. Gregg, N. C. Grover, Montrose W. Hayes, W. W. Horner, Joseph Jacobs, Royce J. Tipton, and Thorndike Saville], in which the need for a manual of procedure covering snow-surveying was pointed out. With the expanded snow-survey program brought about since July 1, 1935, through Federal sponsorship of this work in western United States, the need for such a manual has become urgent. Furthermore, there has developed need for publication of informative material on the principles of snow-surveying and the purposes to be served by the activity.

At present snow-surveys are being made under a unified plan throughout the 11 western states of this country and over contiguous areas of Canada. Appraisal of the snow-cover over so vast a territory has entailed the making of approximately 700 surveys simultaneously at widely separated locations in rugged, mountainous country during winter. The task is made possible through the cooperation of hundreds of different agencies having employees who are strategically stationed for the purpose. It is estimated that the services of approximately 2000 men are gratuitously furnished for the winter field-work in this way. To set up a dependable organization of this sort for an undertaking of so enervating and hazardous a nature and one which calls for both skill and unusual fortitude has required: First, that each of the many cooperators be convinced that the purposes served by the activity justify their participation in it and, second, that the men who are sent out to make the surveys are thoroughly informed as to the requirements. This educational groundwork has been laid, so far, principally by contacting the officials of agencies selected as cooperators and by demonstrating snow-survey procedure to the men who make the surveys. During the four years that this course has been followed sufficient experience has been gained to justify preparation of a bulletin which will take the place of, or at least supplement, the personal supervision of field-work that has heretofore been necessary.

The progress made towards issuing this bulletin gives promise that it will soon be available and that it will serve the long-felt need for a text on snow-surveying. At present it is in manuscript form awaiting its turn to be published as a United States Department of Agriculture bulletin. It embodies the experience and ideas of the Western Interstate Snow-Survey Conference as a whole. To begin with, the field-force was thoroughly canvassed for suggestions. This material was then assembled and circulated for criticism. Finally at a meeting held in Salt Lake City on October 17, 1938, a group of leaders in snow-survey work decided upon the contents and form of the manuscript which has been submitted for publication.

Since it was the consensus of opinion that the principles and purposes as well as instructions in procedure of snow-surveying should be included in the proposed bulletin, the title "Principles and practice of snow-surveying" was adopted. As the manuscript now stands the first 16 typewritten pages deal with the prescribed plan of snow-surveying and the purposes served by it. Thereafter 43 typewritten pages are devoted to instructions and suggestions to snow-surveyors. The highlights of the first section are contained in a list of 12 uses which are made of the snow-survey data and the water-supply forecasts which are based upon them. They are cited as follows:

Irrigation water-supplies--The accurate forecast of the amount of water that will be available, which is made possible by snow-surveys, guides farmers in planting their crops and permits more efficient operation of irrigation-works.

Flood-control--Snow-survey data indicate the presence or absence of potential flood from melting snow. Other factors such as temperature-variation from normal and occurrence of heavy rainfall must be considered along with snow-cover conditions in order to accurately predict when floods will occur and the heights which will be reached by the water. The River and Flood Division of the United States Weather Bureau, as well as other governmental units concerned, such as Corps of Army Engineers, are promptly supplied with all snow-survey data for use in this connection. If reservoir-capacity is available, there is opportunity to use the snow-survey data without considering other factors to reduce flood-hazard. For, if it be known from the snow-cover runoff relationship that more than ample water will be forthcoming from streams to fill irrigation and water-power reservoirs after the major flood-peak has passed, then such structures may be safely used to some extent as flood-control works during spring freshets. Such is the procedure usually followed and thereby flood-damage is being averted at least in some degree.

Water-supplies for hydroelectric-plant operation--Many private power-companies have employed snow-surveys for this purpose for years. The procedure is especially necessary where water is used both for irrigation and for generating electric power. Such is the case at Boulder Canyon Dam. Here, as in other cases which might be cited, the economy of generating as much firm power as possible and at the same time withholding enough water for irrigation makes it necessary to know how much water the mountain snow-cover will yield.

Watershed-protection--Much importance is attached to snow-cover data, particularly by the United States Forest Service, as a means for correctly anticipating forest-fire hazard and grazing conditions. A forewarning that forests will be dry affords the opportunity to put into effect measures which aid in preventing and controlling fire and in avoiding overstocking the range.

Stock-water--Water is so scarce at times on some range-lands that the flow of springs is the limiting factor in use that may be made of the feed. The flow of such springs may be predictable through correlation of their past performance with snow-cover data, thus affording a proper basis for granting grazing privileges.

Municipal water-supply forecasting--Cities which depend upon storage, stream-flow, or springs for their water-supply are among the interests which are benefited by such forecasts. Notably in the cases of Los Angeles and Denver a great deal of attention is given to snow-surveys for this purpose.

Estimating snow-load--The ease with which snow-density measurements may be procured with standard snow-sampling equipment has prompted its use for determining the snow-load which structures must be designed to withstand. Also, snow-density measurements are being made in the same manner in order to accurately specify power necessary to open snow-bound roads.

Farm Loan servicing--Attention is given the forecasts, particularly by Federal Land Bank, in connection with farm loans to the end that farm operations may be restrained or encouraged in accordance with irrigation water-supply outlook.

Crop-estimates--The Federal crop-reporting service, as well as other agencies concerned with statistics relating to prospective crop-production, use snow-survey results as indicators of the types of crops that will be planted on irrigated land and of prospective yields of crops. It is recognized in this field that promise of an ample supply of late water leads to the planting of late-maturing crops, while only early-maturing crops will be grown if it be known that the water-supply will be short--particularly during the late growing season. It is recognized too, of course, that the water to be available in irrigated areas is the major limiting factor in yield per acre of crops planted. Thus irrigation water-supply forecasting is helpful in predicting not only yield per acre but also, in many areas, the acreages which will be planted to various crops.

Mining operations--Water-supply is frequently the chief concern in planning mining operations--particularly so in placer mining and in the operation of smelters. Accordingly there has developed within this industry considerable interest in results of the snow-survey work.

Care and protection of wild life--The Migratory Waterfowl Division of the United States Biological Survey operates numerous inundated areas throughout the West as feeding grounds and refuges for wild life. In most instances elaborate systems of dikes and diversions for extending or restricting the flooded areas in accordance with amount of water available and for regulating the depth of water have been required. Water-supply forecasts based on snow-surveys are helpful in effecting the best operation of these layouts.

Industry and commerce--The water-supply outlook is of general interest throughout the West because production, trade, shipments, banking, and employment all follow somewhat the water-supply trend and in case of serious drought may be most adversely affected.

In the second and principal part of the manuscript the intent is to set forth all of the information which a snow-surveyor should know. The following outline of this section will give an idea of how complete this part of the text is.

Description of snow-sampling equipment: Federal equipment; Mount Rose equipment; Utah equipment; tools.

Care of snow-sampling equipment: Justification for careful handling; keeping tube free from dents; repair and replacement of cutter; keeping duraluminum threaded couplings from seizing; using spanner wrenches for uncoupling tubes; avoiding bending tubes; keeping sampler coated with paraffin or shellac; keeping balance accurate; cleaning and drying equipment after using; carrying equipment in case or with harness.

Snow-sampling procedure: Acquaintance with snow-course location; locating the specified sampling points; assembling the sampler; weighing the empty sampler; cutting a true core of the snow-cover; measuring the snow-depth; retaining the core while withdrawing the sampler; measuring the length of core; weighing the core; dumping the core; sources of error and their elimination; procedure while under stress; recording the notes.

Field office-procedure: Computing field-notes; transcribing field-notes; reporting results by telegraph; reporting results by radio and telephone; forwarding original field-notes; retaining copy of notes at station of chief snow-surveyor; reporting in case there is no snow.

Improvement and maintenance of snow-courses and facilities for snow-surveys: Safeguarding desirable features of snow-courses; improving ground-conditions for snow-sampling; better marking of courses; making trails safer for travel; improving and supplementing shelter cabins; equipping and stocking shelter cabins.

Winter travel--means and safeguards: Travel on skis or snowshoes; crew requirements; dress; travel kit; first aid.

U. S. Bureau of Agricultural Engineering,
Boise, Idaho

DR. J. E. CHURCH suggested one more item to be included in the manual, that is, the introduction of instructions as to procedure or methods in treating cases of cramps, frost-bite, snow-blindness, etc., not usually treated in first-aid manuals. Dr. Church related experiences from his personal acquaintanceship.

## CALIFORNIA COOPERATIVE SNOW-SURVEYS: DIRECTIONS, SUGGESTIONS, AND HINTS FOR SNOW-SURVEYORS

Fred H. Paget

(Since California had also prepared directions for its snow-surveyors, it was requested that these be printed as a part of the Proceedings for the additional experience contained.)

### I--Care of sampler

(1) Keep free from dents
(2) Keep coated with paraffin or shellac
(3) Keep threads free of foreign matter
(4) Keep cutter sharp
(5) Changing the cutter
(6) Carrying the tubes

(1) Keep free from dents--Dents can be removed by using a short cylindrical plug of steel (a swedge) of a diameter just a little less than the inside diameter of the sampling tube. This swedge, if provided with a rounded top, can be shoved through the damaged section of tube, thus forcing the dents back out. Gentle hammering on the exterior of the tube with the swedge in close contact inside will result in a smooth-finished job.

(2) Keep coated with paraffin or shellac--The steel sampling tubes are found to work better with shellac. The duraluminum tubes work best when coated with paraffin. The coating should cover the tube inside and out. After several years of use with the tubes touched up with shellac from time to time, the inside of the tubes will become very rough and it will then be necessary to remove the old shellac entirely and make a fresh start. The old shellac can be cut out by soaking the tube in a warm bath of commercial Oakite solution. If no Oakite or similar caustic solution is available, the old shellac can be removed mechanically with a tight-fitting, coiled-spring flue-brush screwed to the end of a 1/4-inch pipe. To give the tube a final polish, fine emery cloth and steel wool should be used.

After the steel tube is entirely clean inside and out, a coating of shellac should first be put on the outside with an ordinary paint brush. After this is dried the inside can be coated using a swab on the end of a rod. When doing the inside it is better first to cover the slots in the tube with adhesive tape--after the outside coating of shellac has dried. A tight-fitting swab should then be inserted to within 3 inches of the free end. The 3-inch space should then be filled with shellac and with the tube held vertical the swab should be worked up and down with short strokes, gradually working the swab down to the lower end. This gives the inside a thorough even coating, the adhesive tape preventing the shellac from escaping through the slots and messing up the outside of the tube that has already been coated. The tube should then be stood on end until it dries, after which the adhesive can be removed and saved for future use. Two coats of shellac make a more lasting job than one, but one coating is sufficient if the tubes are worked over every year.

The duraluminum tubes should be coated with paraffin. This is best applied by heating the tubes in an oven to a temperature of about 300°. The paraffin to be used should be gradually heated in a dish until it melts, being careful not to burn it. The tubes when taken from the oven should of course be handled with heavily-padded gloves. The outside of the tube is then painted rapidly with a layer of the melted paraffin and, immediately after, a swab dipped in the wax is run up and down the inside. A little practice at this will enable one to get a good smooth job without lumps inside and out.

(3) Keep threads free of foreign matter--In shellacking the steel tubes and waxing the duraluminum ones, care should be taken to keep the shellac and paraffin from getting into the threads of the couplings. An easy way to prevent this is to coat both the male and female joints with a thin layer of vaseline which can be wiped out after the coating job has been completed. It is a good idea, after a coating job has been done, to screw all the lengths of the sampling tube together to make sure that the threads are clean and that the couplings fit together easily with the tubes in the proper order. Any dirt or foreign matter gumming up the threads can be removed with a wire brush. This will do away with the possible annoyance of having the tubes refuse to go together at the snow-course, where the thread-cleaning would have to be done under adverse conditions with the point of a knife, a rusty nail, or some other makeshift instrument.

(4) Keep cutter sharp--The cutter should be kept sharp for cutting easily through hard snow-crusts and ice-layers that may be found in the snow-pack. If not too dull the points of the cutter teeth can be sharpened up with a fine half-round file. The filing should be done on the sloping sides of the teeth and as little as possible on the vertical sides. After filing the teeth sharp, care should be taken to remove any burred or feather edges.

(5) Changing the cutter--A spare cutter is generally supplied with each set of equipment, and if the cutter is damaged beyond resharpening with a file, the old cutter should be removed and replaced with a new one. The cutter is held in the end of the tube with solder only and can be removed by heating over a fire, rotating the tube so that it heats fairly even all around. When the end of the tube gets hot enough so that the solder melts, the old cutter can be removed with a pair of pliers. Keeping the end of the tube hot, the new cutter is heated until the

tinning of solder on its shank becomes molten, when it should be pushed into the end of the tube. If it does not go in readily but sticks part way, it can be rammed home by quickly turning the tube vertical and pressing the teeth of the cutter against the floor. Sometimes a slight blow or two against the floor will be needed.

(6) Carrying the tubes--In carrying the tubes when they are in 60-inch lengths, they should be tied securely to the outside of the pack, vertically on the sides. In this position they will not interfere when passing between trees that may be close together. If the tubes are in 30-inch lengths, they can be carried in the regular canvas sack provided, with the sack lashed securely to a Trapper Nelson pack-board. Each compartment of the canvas sack should be numbered on the outside with the length of the tube carried inside, such as 0-30 inches, 30-60 inches, etc., and in putting the tubes away, care should be taken that the correct tube is put in the corresponding pocket. This will save time and confusion when putting the tubes together at the course.

## II--Snow-sampling procedure

(1) Refer to sketch of snow-course
(2) Measure correct distances
(3) Tubes put together in sequence
(4) Weighing the entire tube empty
(5) Don't cling to sampling tube
(6) Getting the sampler down
(7) Removing dirt from cutter
(8) Weighing the snow-core
(9) Recording the notes
(10) Causes of sticking snow
(11) Errors--causes and detection
(12) Procedure when under stress
(13) Care of sampler after measuring

(1) Refer to sketch of snow-course--Every snow-survey crew should have with them a sketch map showing the layout of each snow-course they are to measure. Work should start from the end designated on the sketch as being the beginning of the course and the samples should be measured, recorded, and numbered in the same order as shown on the sketch.

(2) Measure correct distances--The distance from the end-marker to the first sample should be carefully noted and also all interval distances between the samples as shown on the sketch. On many snow-courses the intervals will be uniform, either 25, 50, or 100 feet, but in other cases the distances will be of irregular lengths. The sampling points are laid out in the summer when the ground-surface is exposed and the irregular distances where they occur are for the purpose of avoiding obstacles on the ground, such as fallen trees, stumps, stones, water-courses, or uneven, irregular depressions. Because of relations developed between runoff from the watershed and the snow-water content at these sampling points of the snow-course it is very important that samples should each year be taken at exactly the same place or as closely as possible thereto.

At a key-course that is measured several times during the winter, it will sometimes be found that the dirt from the cutter thrown on the snow during an early measurement will have caused a pot-hole or cupped depressions to melt in the snow at the sampling point. This melting is purely a local accident and is not influenced at all by the amount of snow on the watershed in general. In such cases to avoid error and show the correct amount of snow at the course, the samples should be taken at a sufficient distance out at right-angles from the actual point called for, to be beyond the zone of melting caused by the foreign dirt thrown on the snow. Here as in other cases it is essential that the snow-surveyor use his common sense and not blindly adhere to specific instructions which if followed to the letter result in poor or worthless results.

(3) Tubes put together in sequence--Before measuring, the minimum number of snow-tubes should be fitted together that will reach to the ground below. In putting the tubes together, care should be taken that the numbering on the outside of the tubes is in sequence, reading consecutively from "0" to the maximum length of the tube used. This will prevent wrong measurements of depth due to having a tube out of its proper place.

(4) Weighing the entire tube empty--Before sampling, the connected tube with the driving wrench attached should be placed on the scales. With the Mount Rose equipment the indicator of the scales should be set to zero by means of the knurled nut at the top of the scales-case. With the Federal tubular scales this is not possible and the weight of the empty tube must be noted and recorded in the place provided in the notes.

(5) Don't cling to sampling tube--Before starting to take the sample, the operator should make sure that he is standing in a secure stable position from which he can work without clinging

to the tube for support as the tube can be easily bent if it is used for support on a side-hill, especially after a portion of the tube has been sunk in the snow.

(6) Getting the sampler down--In starting to sample care should be taken that the tube is empty each time. This is easily done by throwing the tube up vertically over the head and looking through the tube with the far end pointed at the sky.

Having made sure that the tube is empty it is held in a vertical position with the cutter end just above the snow. The downward stroke is then started and if the snowpack is not too deep or too dense the tube will penetrate all the way to the bottom without needing any rotation or undue pressure. If the snow is dense it will generally be found necessary to put some pressure on the driving wrench and rotate it in a right-hand direction to gradually force the tube through the snowpack to the ground below. In some cases it has been found necessary to stand on the driving wrench in order to get more weight on the tube. When this is done, care should be taken that the driving wrench is within two feet of the top of the snow and one operator should steady the other while gaining his standing position upon the wrench. A thrust of the body from the knees up, with the feet kept firmly on the handle of the wrench--never jump up and down--will often force the tube down through an obstinate snow-crust or ice-layer.

During the spring of 1938 it was found throughout California that the great depth of snow laid down in the January-February storm-period, without any intervening time for consolidation or packing as the snow accumulated, resulted in a layer deep in the snowpack of a flocculent non-crystalline snow which the snow-surveyors termed "corky snow." This had a tendency to choke the throat of the cutter. With the throat of the cutter choked, snow will not enter the tube no matter how much the tube is weighted and rotated, downward progress being made merely by pushing the tube through the snow in the same manner as a solid stick. For this particular type of snow, it was found that good results could be obtained by allowing the tube to penetrate the snow gradually under its own weight with very little pressure, if any, by the operator; the tube being slowly rotated a small amount, first in one direction and then in the other. Sometimes this required about ten minutes to take each sample but it was the only way found possible to get the tube down and get the sample in one core-length. This method has been dubbed "tickling the tube through."

In cases where the tube cannot be put down either by rotating, forcing, standing on the driving wrench, or tickling, a sample to be taken at all must be taken in two pieces. The first piece will be from the surface down to the hard layer which chokes the cutter or stops the tube going down. When this layer is reached and before the tube is withdrawn, the hole is enlarged by rotating the top of the tube in a circle, making the hole cone-shaped. While rotating the tube, care should be taken to keep the back of the tube against the side of the hole so that foreign snow will not have a chance to enter the tube through the slots. The tube is then carefully withdrawn and the weight of the first core down to the hard layer recorded. This partial core is then dumped out and the tube gently lowered down into the enlarged hole, care being taken to center the tube exactly to prevent knocking snow down from the sides. If some snow does accidently get knocked down, this will be of loose texture and can oftentimes be removed from the top of the core of the lower section before it is weighed.

With the tube empty starting at the hard layer at the bottom of the first hole it is usually possible to continue from this layer on down to the ground below without having the crust clog the cutter as it will do with half a length of core already in the tube above. By taking the sample in two cores in this way it is often possible to get a sample that could be secured in no other way. In extreme cases it has sometimes been necessary to take the core in three sections in a similar manner. This method is not advocated when a single core can be got by any other means as error may result causing a water-content to be measured greater than actual.

The experienced operator can usually tell when the tube has penetrated the snowpack and has come in contact with the ground. A layer of ice or a hard layer of heavy snow will after one or two rotations give a slick, hard greasy feeling, whereas grass roots, gravel, or rock will have a somewhat rough feeling and mud will have a gummy feel. Where the course is laid out on a rocky surface, great care is needed not to dull the cutter by needless rotation after the tube is down.

(7) Removing dirt from the cutter--When the operator feels that he has penetrated the snowpack, he notes the depth of the snow by reading the tube graduation even with the surface. He then pulls up the tube a slight distance and observes the upper end of the snow-core through the slots in the walls of the tube. Both of these measurements--snow-depth and core-length--are observed to the closest inch only.

The entire tube is then withdrawn and the throat of the cutter examined for evidence that the tube has been all the way down. Grass, twigs, dirt, sod, earth, or mud, etc., are all positive indications that the tube has been through. The dirt in the cutter should be carefully removed with a slim tapering knife-blade before the core is weighed. The depth to which the dirt occupies the tube should be deducted from both the snow-depth and the core-length and the true net values for these recorded in the notes.

(8) Weighing the snow-core--When the foreign matter has all been removed from the lower end of the tube, the tube with the snow-core is placed on the scales and the reading of the indicator noted. With the Mount Rose scales, this reading gives directly the water-content of the snow-core in inches of water. With the tubular Federal scales, this final reading is the gross weight of the tube and the snow-core, from which the predetermined weight of the empty tube must be deducted in order to arrive at the net weight of the snow-core in inches of water.

When weighing the tube, it will be found best to hang the scales from a pole instead of holding them in the hands as the latter method is unsteady and makes the scales hard to read. A scale-pole for this use is sometimes provided where the snow-course is easily accessible. Where the course is at some distance, however, this pole is rarely taken along, the snow-surveyors preferring to pick up a suitable pole at the site, or failing this the scales can be suspended from the tip-end of a ski or snow-shoe.

The scales will sometimes act in a sluggish manner, not always coming to rest in the same place with the same load. In such cases, grasp the outer case of the scales and shake the scales slightly, with a gentle rattling sidewise motion; this will allow the indicator to come to its proper position of rest.

(9) Recording the notes--In recording notes, the white pad should be used in the field and not the pink, as the white paper is waterproofed and holds up better when exposed to rain and snow.

Snow-depths and core-lengths should have the depth of dirt on the bottom deducted and should then be entered in the notes to the closest inch.

Weights should be entered to the closest 1/2 inch of water.

Under "Remarks" should always be entered the character of the bottom. This gets the observer into the habit of always looking at the bottom and prevents foreign dirt from being overlooked and weighed with the core.

(10) Causes of sticking snow--It will sometimes be found that the snow will adhere to the tube in spite of the shellac or wax coating. This is usually caused by the upper and lower layers of snow being at different temperatures--one above freezing and the other below. On cold days in the winter at midday in the Sun, the upper layers of the snow may be melting while those beneath will be freezing. Later in the season early in the morning or late in the afternoon, the top layers may be freezing while the under layers are at melting temperatures. Either of these conditions will cause the damp portion of the snow gathered in that portion of the pack at or above melting to freeze to the tube when the tube enters that part of the pack which is below freezing. If this situation is encountered and sufficient time is available, it will be found better to wait a few hours until temperatures are equalized throughout the pack before making the measurements.

(11) Errors--causes and detection--Errors in snow-surveying may occur as in any other line of work in which figures are used. Careful conscientious attention to the work in hand will, however, eliminate most of the errors due to faulty reading and recording of snow-depth, core-length, and weight of water-content. Scales should be tested annually for errors due to faulty spring-tension, and if sticking occurs in the field it can be overcome by rattling the scales sidewise as before described.

There are two sources of error, however, which are often overlooked by conscientious observers because they have not been specifically drawn to their attention. Even though dirt may be brought up in the cutter, indicating that the sampling tube has been all the way through the pack, the weight of the core may not be a true indication of the water-content of the snowpack. This may be because of one of two reasons: (a) Incomplete core; (b) ponded foreign water.

(a) With the incomplete core, the cutter has become choked on its way down and during a portion of the last part of its descent has not allowed any snow to enter the tube but has merely pushed through the snow in the manner of a solid pointed stick. This error can generally be detected in the field by an alert observer as the weight for the depth of snow will be out of proportion to the relation already established at prior samples where there was no doubt as to accuracy. Where a light core is evident, the sample should be taken over again about 12 inches away from the first hole, until the weight of the sample corresponds in a general way with those correct ones already taken or else the reason for the difference should be discovered in the field and a note as to the reason should be written in the column provided for remarks. It is impossible to tell the reasons for non-conformity of samples by an inspection of the notes unless the man in the field has been thoughtful enough to make a note of the reason as he has observed it in the field. In the absence of any remarks, these erratic samples must of necessity be thrown out when the notes are being worked up in the office, which in most cases will be the correct thing to do. It is felt, however, that in some cases if the observer were to take the trouble to enter a few remarks they would not have to be thrown out and better accuracy would result. If one of the snow-surveyors can run a slide-rule, it is to the advantage of the party to take one along with them and compute the density of each sample as the work is carried on. Any sudden jump in the general relationship of density would indicate an error, unless such discrepancy could be accounted for in the field at that time. The density should not change greatly from sample to sample, although it may tend to be somewhat less at the edge of a clearing than it will be in the center where, due to the exposure to the Sun's rays, more settlement will have taken place and the density will have correspondingly increased. The observed changes in density from the edge of the clearing should be gradual, however, and not in jumps unless there is some evident reason for it. Any such reason should be entered by the snow-surveyor under "Remarks."

(b) Ponded water is generally due to poor water-drainage of the area upon which the snow-course is laid out. Water runs out of the melting snowpack from the slopes surrounding the snow-course and due to flatter slopes at the snow-course itself ponds up momentarily under the snow at the snow-course site. The amount of this ponded water will depend upon the lay of the land and also upon the amount of melting that has taken place upon the slopes before the time of the snow-measurement, and will not at all depend upon the character and amount of the snowfall during the year. For this reason any gathering of water beneath the snow at the snow-course, which is not also met with on the sloping portions of the watershed beyond the limits of the snow-course, upsets the relation between snowpack as measured at the course and snowpack as existing in the surrounding country of which the snow-course is supposed to be representative. It is recommended, when the operator finds water running from the end of the tube after withdrawing a sample, that he does not bother to weigh the core at all as the weight will include a large amount of foreign water and so would be meaningless as representative of the general area. It is recommended that in such cases the depth of the snow alone be recorded with dashes in the spaces reserved for length of core and weight of core and the words "Ponded water" under remarks. The mean density of snow for the snow-course can be determined in such cases from those samples which are good--without ponded water--and this density, so derived, can be applied to the average depth of snow at the course, which average will take into account the depth at all the sampling points including those at which water was found.

(12) Procedure when under stress--Under certain conditions and where quite a few samples are to be made, it may be found that there is not enough time to take samples at all points. In such cases, samples should be taken and weighed only at every second or third point, while at all intermediate points the depth of snow only should be measured. This procedure will usually be unnecessary and should be resorted to only when extremely difficult sampling conditions or approach of darkness make it almost, if not entirely, impossible to complete the entire survey as called for on the sketch.

(13) Care of the sampler after measuring--After the sampling has been done, the tubes, if they are to be put away, should first be carefully dried. This can be done by wiping the outside with a cloth and pulling a rag on a string through the inside.

### III--Traveling

By far the greatest part of the work necessary to secure a set of snow-measurements is expended in traveling to and from the snow-courses. For this reason some thought should be given to methods of making winter snow-travel as easy as possible.

In most territory, skis are preferable to snow-shoes since they are but slightly less efficient in climbing and much more efficient when going down hill. Men unaccustomed to skis can quickly learn to be efficient at cross-country touring travel such as is necessary on snow-survey work where high-speed Telemarks and Christianas are unneeded.

Steep slopes should be avoided in favor of more round-about or zig-zag routes with more gradual slopes.

Ski-socks, while permitting climbing on a steeper grade, are in general not necessary, as the proper ski-wax intelligently applied will in most cases do as well. Ski-socks are essential, however, on steep narrow trails where there is not much snow on the ground. Good skis with strong adjustable bindings as well as strong, well-fitting ski-boots are essential.

On a long trip it is generally found better to get a very early start in the morning when the crust is frozen. During the early hours traveling can often be done over the crust on foot without the use of skis. At such times the skis may be towed behind by means of a thong threaded through a hole bored in the toe of each ski.

In traveling before daylight each member of the party should have a headlight--either a miner's headlight which burns carbide, or a Forest Service type flashlight with a head-set reflector. The miner's lamp is more efficient in terms of hours of light for the weight carried and throws a desirably wide beam. It has the disadvantage that it may go out in a high wind.

Warm underwear should be worn by the men, allowing lighter outer garments. A windproof jacket with a parka hood is also recommended. When the men stop traveling, either to take a rest or to measure a snow-course, a sweater should be slipped on to prevent cooling off quickly and thus catching cold.

If caught out in a storm at night it is better to hole up in a sheltered place and wait until dawn. A fir tree growing in the open or at the edge of a clearing will generally have dense foliage and a snow cup around the trunk of a tree, making an ideal place for shelter.

If a fire is made on the snow, green branches should be placed underneath to prevent the fire from melting its way down into the snow, which will put it out.

A "snow-surveyor's rag," a cloth about 2 feet wide and 5 feet long, slipped through the belt, will be found to have a myriad of uses.

A thong or lash tied in a bow-knot over the ankle will prevent one losing a ski if the binding slips off the heel. The bow-knot will allow the binding to be released easily when it is desired to take it off.

A small empty can tied on a thong is handy for drinking purposes. This thong tied to the end of a ski-pole will reach down and get water at the bottom of a deep hole or from a stream with steep snow-banks at the sides.

Dark glasses should be used to prevent snow-blindness. The ordinary spectacle-type are best as there is good air-circulation behind the lenses which hinders "sweating up."

To prevent snow-burn a solution is recommended made by dissolving one ounce of tannic acid powder in three ounces of alcohol and adding one tablespoon of glycerine. Apply as a lotion before going out. It washes off readily.

A small roll of adhesive should be carried in the pack. A piece placed over tender spots that may chance to develop on the feet will prevent painful blisters.

Difficult trails to the snow-courses should be signed with markers about 80 feet apart so that they can easily be found even if it is snowing. In California many trail-markers have been made from old automobile license-plates. The black figures on an orange background show up well in the trees. These license-plates are bent in the form of a "T" and nailed so that they are easily seen from either direction. A similar marker can be cut from a board 1- by 6-inch board. These should be dipped in orange paint before being nailed up.

## IV--Stocking cabins

Cabins should contain stove, lamp, table, chairs, cots, mattresses, bedding, cooking utensils, and dishes, and should be stocked each year before the advent of winter with an adequate supply of food and fuel.

The following is a sample grub-list which we suggest should be used in stocking a cabin where the men expect to stay for one night. The supply, of course, is more than ample for one day but this is desirable as there is always the chance that stormy weather or other reasons may cause the men to stay over a day or two extra at any of the cabins along their route.

### Sample grub-list for snow-survey shelter-cabin

1/2 pound black tea
5 pounds sugar
1/2 pound coffee
1/2 pound chocolate
1 package salt
1 can pepper
6 cans milk, small
2 cans milk, tall
1 package Swansdown flour
1 package Aunt Jemima pancake flour
1 package H. O. oats, small
1 package corn-meal
1 can baking powder, small
2 cans butter, Golden State, 12-ounce
1 can Crisco, small
2 cans brown bread, B. and M.
1 package Melba toast
1 package Rye Krisp
1 dozen eggs, large
2 cans breakfast sausage, Hormel
2 cans baked beans
3 cans soup, assorted

2 cans potatoes
2 cans string beans
2 cans corn
2 cans spaghetti
1 can syrup, Log Cabin, small
1 bottle mixed pickles
1 can chicken, Hormel
1 can corned beef
1 jar pickled pig's feet, Hormel
1 jar jam
1 jar cheese
1 package assorted cookies
1 pound rice
1 pound noodles
1 jar peanut butter, small
2 cans grape-fruit juice
2 cans tomato juice
2 cans grape fruit
2 cans pears
2 cans peaches
6 bars nut chocolate, Hershey
1 box raisins

Freezing has no detrimental effect upon any of the above food the first year. It is a safe precaution, however, each year to remove and replace all freezable goods not consumed the previous winter.

A Star can-opener or one of similar type, that removes the entire top from the can with a smooth cut, should be provided for each cabin. There is too much danger of a man cutting his hand on the jagged edges raised by an old-fashioned can-opener.

California State Division of Water Resources,
Sacramento, California

## FORECASTING STREAM-FLOW

### IMPROVEMENTS IN THE METHODS OF FORECASTING STREAM-FLOW

Carl Elges

The first forecasts of stream-flow from snow-surveys made by Dr. J. E. Church were for the Truckee River and the level of Lake Tahoe. These forecasts were in percentages of normal based on only the first year's measurement expanded by comparison to the snow-depth record at Summit and adjacent stations. Dr. Church computed the snow-depth at Summit to be 86 per cent of normal and assumed his first snow-survey water-content to also be 86 per cent of normal, thereby arriving at a figure representing a normal for that snow-cover. This method is used to the present date where there is a lack of runoff-data.

When three years' record had been accumulated, namely, 1909, 1910, and 1911, he revised his normals for courses and runoff, making them the averages for those three years. A further three years of record were then obtained before another revision was made. It so happened that the six-year averages, 1909-1914, were approximately equal to the 1909-1911 averages. Some of these normals were used until after 1920 before they were brought up to date. Thus the percentage-of-normal system started when snow-surveying began.

The percentage system was originated in order to eliminate the numerous factors that must be considered by the quantitative system and because it is practically impossible to quantitatively establish the amount of water in storage in the snow on a watershed. The percentage system uses a snow-course as an indicator of water-storage in that locality. By comparison to previous records of snow-cover and runoff either by charts or graphs, this indicator can successfully be used to forecast the major runoff of a stream. The principles of this system are in use in all modern methods of forecasting today.

When snow-surveying was first started there were only a few snow-courses, and to arrive at an average for the basin a simple arithmetical average was used. However, when more courses were laid out, refinements were necessary so that courses were not given too much weight in the average when they represent little power to produce runoff. The zoning system was then developed whereby the basin is divided into altitude-zones and the snow-courses in each zone are averaged and given a weight, in calculating the average water-content for the basin, in accordance with the percentage of the basin that the zone represents.

Another system of zoning used is that of zoning various sections of the basin in accordance with the precipitation and area. For the average in the Lake Tahoe basin, for instance, twice as much weight is given to the western courses as to the eastern ones because the power to produce runoff is much greater on the west due to the greater drainage-area and far heavier precipitation.

The next step in zoning is to make a combination of the two previously-mentioned systems by applying first the altitude-zones, then combining sections of the basin to procure a sectional average, and then weighting these sectional averages in accordance with the power to produce runoff.

A further development is to weight the altitude-zones in accordance with the water-content of the snow-cover in that zone so that the upper zones where considerable water is held in storage will be given more weight in the average than the lower zones that may represent little or sometimes no water.

I have chosen the Lamoille Creek basin in eastern Nevada as an example to show the different averages arrived at for 1938 by three of the above systems. The figures follow.

Straight arithmetical average

| | |
|---|---|
| Average of 7400-foot course | 8.9 inches |
| Average of 9000-foot course | 17.2 inches |
| Arithmetical average | 13.0 inches |

Weighted by altitude-zones

Area above 8500 feet equals 1.9 times the area below 8500 feet. The snow-course at 7400 feet represents the lower zone and the one at 9000 feet represents the upper zone. Therefore, the 9000-foot course is given 1.9 times the weight given the 7400-foot course.

$$8.9 \times 1 = 8.9$$
$$17.2 \times 1.9 = \underline{32.7}$$
$$41.6/2.9 = 14.3 \text{ inches}$$

Weighted by altitude-zones and by water-content

The ratio of altitude-zones given above is 1.9 to 1. The ratio of water-content of upper to lower zone = 17.2:8.9 or 1.9:1. In the combined system then the upper zone is given 1.9 times 1.9 or 3.6 times as much weight as the lower zone.

$$8.9 \times 1 = 8.9$$
$$17.2 \times 3.6 = \underline{61.9}$$
$$70.8/4.6 = 15.4 \text{ inches}$$

Comparison of results

| | |
|---|---|
| By arithmetical average | 13.0 inches |
| By weighting altitude-zones | 14.3 inches |
| By weighting altitude-zones and water-content ratio | 15.4 inches |

Since all attempts to forecast runoff begin with the average snow water-content on the watershed, it is important to give the methods of arriving at this average serious consideration and it is believed that in many cases the accuracy of forecasts can be improved by using some of these methods. Of course each basin remains a problem in itself and a method that is suited to one watershed may not apply to another at all.

Another example of computing average water-content follows. This case is for the Truckee River basin for 1938 as worked up by Professor H. P. Boardman. Professor Boardman prefers to use percentages of normal, and all figures of water-content will therefore be in percentages. This example brings out another system of weighting, by size of drainage-areas, which was not used in the Lamoille case.

Computation of average water-content for Truckee River basin, 1938

Mean average water-content, West side high level 134.7 per cent of normal
West side low level 159.8
East side high level 129.1
East side low level 193.4
Ratio of water-content on high courses to low courses = 2.06:1
West side of basin:
2.06 × 134.7 = 278
1 × 159.8 = 159.8
437.8/3.06 = 143 per cent
East side of basin:
2.06 × 129.1 = 266
1 × 193.4 = 193.4
459.4/3.06 = 153 per cent
Ratio of West side area to East side area = 1.48:1
Ratio of West side water-content to that on east side = 1.65:1
Combined ratio = 1.48 × 1.65:1 = 2.4:1
Average for basin:
2.4 × 143 = 343
1 × 153 = 153
496/3.4 = 146 per cent of normal

After the average water-content on a watershed has been determined, the forecaster is ready to analyze the data and arrive at a forecast. Various methods are used in making comparisons with past records of water-content and corresponding runoff. The oldest method which is still in use is the percentage system. Some agencies use this system but use only runoff and snow water-content records of equal length, thus making it a percentage of the mean system. This makes it necessary to revise the figures each year and compute new means and new percentages. Figure 1 furnished by the Department of Water and Power, City of Los Angeles, is plotted in percentages of the mean.

Usually with the percentage-of-normal system an attempt is made to expand the snow-cover mean water-content to a long-time average by comparison to available runoff-data so that a revision will not be necessary for a number of years. Even when but a few years of record are available, a normal is set up and used for a number of years before a revision is made, for a considerable amount of work is involved in reworking the figures. Furthermore, the forecaster, after fixing in mind the normals, can readily compare the various years of record, make comparisons between basins, note any divergencies in snow-cover, and thus more fully understand the conditions. This is particularly valuable where personal judgment is used in forecasting.

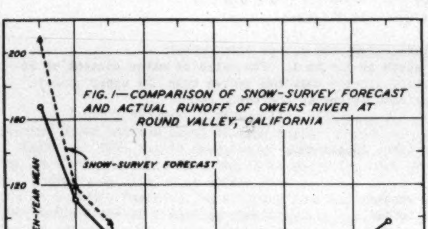
FIG. 1—COMPARISON OF SNOW-SURVEY FORECAST AND ACTUAL RUNOFF OF OWENS RIVER AT ROUND VALLEY, CALIFORNIA

Perhaps the most convenient method in use is the direct curve recently brought into use by the California Cooperative Snow-Surveys and the Bureau of Agricultural Engineering. It is quite valuable where a good correlation is found between snow-cover and runoff under which conditions a forecast can be arrived at by merely referring to the graph. Figure 2, furnished by J. C. Marr, is a very good example of the direct curve.

The direct method employs no new principles. The water-content is still used as an indicator of runoff. All the desirable factors of the percentage system are retained. However, it has certain advantages over the

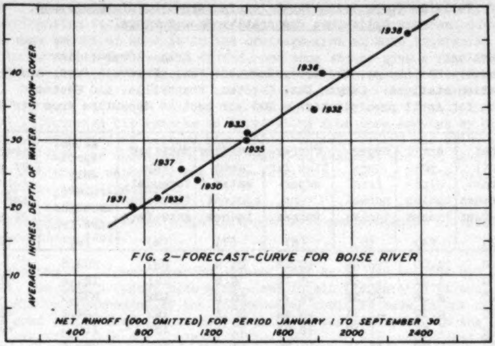

FIG. 2—FORECAST-CURVE FOR BOISE RIVER

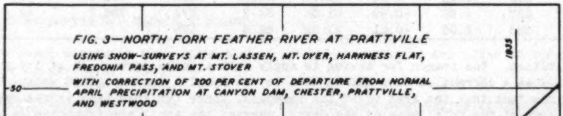

FIG. 3—NORTH FORK FEATHER RIVER AT PRATTVILLE

USING SNOW-SURVEYS AT MT. LASSEN, MT. DYER, HARKNESS FLAT, FREDONIA PASS, AND MT. STOVER

WITH CORRECTION OF 200 PER CENT OF DEPARTURE FROM NORMAL APRIL PRECIPITATION AT CANYON DAM, CHESTER, PRATTVILLE, AND WESTWOOD

percentage systems. It eliminates the rather tedious task of computing normals and the percentages. Furthermore, it offers a means for correcting for fall and spring precipitation. The following example of a correction made for April precipitation was furnished by Fred H. Paget to replace the one described in his paper "Development of snow-surveying in California" which appeared in the Transactions of the American Geophysical Union for 1938 (see Table 1 and Fig. 3).

It should be noted in the example that the correction for the April precipitation is not fixed at 200 per cent but at a figure that will produce the best results when applied to the curve. Mr. Paget gives the following explanation which should accompany the example:

> "You will note that the percentage of departure used on the attached example is 200 per cent, but from this it should not be concluded that the runoff was greater than the

Table 1--Computation-sheet for forecasts by direct method, California Cooperative Snow-Surveys

Basin: Feather Area: Prattville
Snow-courses: Mt. Lassen, Mt. Dyer, Harkness Flat, Fredonia Pass, and Mt. Stover
Precipitation-stations: Canyon Dam, Chester, Prattville, and Westwood
Correction for April precipitation = 200 per cent of departure from April mean normal

| Year (1) | Mean water-content of snow-pack, inches (2) | Normal April forecast, thousands acre-feet (3) | April precipitation, inches (4) | Departure from normal, inches (5) | Correction for departure, inches (6) | Modified mean water-content, inches (7) | Modified May forecast, thousands acre-feet (8) | Actual April-July runoff, thousands acre-feet (9) | Discrepancy of normal forecast, per cent of actual (10) | Discrepancy of modified forecast, per cent of actual (11) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1930 | 23.9 | 220 | 3.00 | +0.49 | +0.98 | 24.9 | 227 | 233.5 | -6 | -3 |
| 1931 | 11.6 | 140 | 1.12 | -1.39 | -2.78 | 8.8 | 121 | 121.4 | +15 | 0 |
| 1932 | 24.9 | 227 | 2.86 | +0.35 | +0.70 | 25.6 | 232 | 233.0 | -3 | -1 |
| 1933 | 23.8 | 219 | 0.77 | -1.74 | -3.48 | 20.3 | 197 | 182.0 | +20 | +8 |
| 1934 | 13.3 | 150 | 1.41 | -1.10 | -2.20 | 11.1 | 136 | 136.0 | +11 | 0 |
| 1935 | 35.3 | 302 | 7.69 | +5.18 | +10.36 | 45.7 | 369 | 369.4 | -18 | 0 |
| 1936 | 30.0 | 262 | 1.92 | -0.59 | -1.18 | 28.8 | 253 | 261.9 | 0 | -3 |
| 1937 | 33.1 | 280 | 1.82 | -0.69 | -1.38 | 31.7 | 272 | 268.7 | +4 | +1 |
| 1938 | 63.6 | 480 | 2.00 | -0.51 | -1.02 | 62.6 | 475 | | | |

precipitation. The reason for having to apply such a large percentage of the precipitation-departure as a correction when adding this to the April 1 mean weighted water-content is due to the fact that the area under the snowpack, above the snow-line, varies between 30 and 40 per cent of the total area of the basin, whereas the April precipitation is applied over the entire basin. It may logically be expected that an inch of April precipitation applied over the entire watershed is from two and one-half to three times as productive of runoff as is an inch of water-content of snowpack applied over 40 or 30 per cent of the watershed, other factors being equal.

"In addition, from purely practical consideration, it would be expected that April precipitation is more effective than is snowpack. During April, when runoff is in progress and the basin saturated, precipitation immediately joins runoff without any large increment of loss by evaporation, percolation, and transpiration. These losses more greatly affect the snowpack."

A soil-priming factor applied in a similar manner has been worked up for the Jackson Lake forecast by J. C. Marr and is fully explained by him in his article "Effect of soil priming by fall precipitation on spring runoff" which appears elsewhere in these Transactions.

Further accuracy will be attained when such factors as soil priming, effect of temperature-departures on runoff, ground-water levels, etc., are more fully understood. However, with present development it appears as though a study of the computation of the average snow-cover on each basin would be very much worth while in developing further accuracy.

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## DISCUSSION

A prolonged discussion followed relative to correction-factors to be applied.

**FRED H. PAGET** described the method of forecasting and the use of a correction-factor, in that precipitation during the month of April is a factor that should be applied to the forecast made on April 1.

**J. E. PHILLIPS** briefly described snow-surveys and forecasts in his territory and brought up the subject of snow-coverage, and what effect the personal element of percentage of coverage would have on forecasts.

**MR. PAGET**, answering Mr. Phillips, explained that a snow-course measurement merely indicates an index, that immediately following a storm the coverage might be approximately 100 per cent, but that drifting following the snowfall might reduce the apparent coverage. However, approximately the same amount of snow is in the drainage-area at both intervals. Snow-courses are placed to be as free as possible from drifts, and thus should give a fair index. The personal element of percentage of coverage on a course has no bearing on the accuracy of the forecasts.

JAMES C. MARR illustrated his remarks on forecasting from snow-surveys by displaying four curves which had been corrected by factors based upon rainfall before and after the snowfall-season. He mentioned that the correction-factor based on rainfall did not give very conclusive results, but felt that ground-water, or the water-retaining capacity of the soil, would be an item well worth further investigation.

CARL ELGES asked Mr. Marr how he would interpret well-measurements, or rather how he would apply them as a correction-factor.

MR. MARR, answering Mr. Elges' question, stated that he as yet has not had a great deal of time to work on it, but that a factor does exist, and in all probability it would have to be worked out empirically. Measurement of the ground-water could be made in the fall of the year. This would give a good estimate of the retention-value of the soil prior to the period of heavy snowfall. He believed that this soil-priming influence-factor when correlated would materially increase the accuracy of the forecasts.

W. A. LANG supported Mr. Marr's argument.

R. D. GOODRIDGE suggested that springs when properly correlated may offer an index in the retention-value of the soil.

MR. MARR, MR. GOODRIDGE, and MR. ELGES then discussed the possibility of using the flow of springs as an index of the retention-value of the soil, to be applied to forecasts. All agreed that this correction-factor seems to a step in the right direction in furthering the accuracy of forecasts.

## THE USE OF PRECIPITATION-GAGE MEASUREMENTS IN FORECASTING THE INFLOW TO LAKE MEAD

O. C. Reedy

(Published with the approval of the Commissioner of Reclamation)

(In connection with this paper, S. O. Harper, acting Chief Engineer of the Bureau of Reclamation, writes as follows to Dr. Church: "I am forwarding herewith a paper prepared by Mr. O. C. Reedy of this office, discussing the plan of the Bureau of Reclamation to utilize measurements of precipitation in conjunction with snow-course measurements as a means of forecasting the probable inflow to Lake Mead. You will note from reading the paper that presentation of the material may be a bit premature in that the Bureau has not made sufficient use thereof to be able to state any conclusions. However, it may be that by presenting our ideas on the subject, and getting other people to think along these lines, we may secure some suggestions as to our plan of attack, and I assure you that these will be welcome.")

With the recent completion of Boulder Dam and the filling of Lake Mead to such a point that within the next few months there is a possibility of the reservoir reaching its maximum capacity, the problem of forecasting the inflow to the lake in such a manner as to permit intelligent reservoir-operation becomes more and more important. The Boulder Canyon Project Act directs that the reservoir shall be operated for (1) river regulation and flood-control, (2) irrigation-needs, and (3) the production of power. As the important source of income is from power revenues, it follows that exceptional skill and judgment must be exercised to secure the greatest possible power output, without sacrifice of flood-control benefits. The storage-capacity set aside primarily for flood-control purposes will adequately care for floods of ordinary magnitude. In years of subnormal runoff, waters may safely be stored in part of the flood-control storage without interference with flood-control operations, and, in years of extremely high runoff, part of the power storage must be used for flood-control purposes to adequately control floods. Since discharges of more than 30,000 to 40,000 second-feet from the reservoir would vitiate the attempts at river regulation and conservation of all inflow in a series of years of low runoff is necessary to maintain the firm power output, it is obvious that there must be in the hands of the operator advance information of what he may expect in the way of a flood in order that he may draw down the reservoir if necessary to permit storage of a large flood or may conserve water in the event the anticipated flood is small. Approximately two-thirds of all the runoff entering the lake comes in the form of spring floods derived from melting snows, and it is to the forecasting of the probable magnitude of these floods that particular attention must be given. The use of the course-method of snow-surveys for this purpose has been frequently discussed, and a paper by the author titled "Application of snow-survey data by the Bureau of Reclamation" was published in Part II of the Transactions of the American Geophysical Union for 1937.

As was mentioned in this paper, there are reasons why the Bureau of Reclamation has felt that snow-survey data alone would not be adequate on which to base an accurate forecast of the inflow to Lake Mead. One of the important sources of difficulty is the complete change that may occur in the snow-cover over the basin during the months of April and May due to late snows. This change has been sufficient in past years to have required a revision of the plan of operation of the reservoir during the spring months. An organization geared to make snow-course readings only once a month cannot be expected to secure data in the middle of the month, but it is not at all difficult to secure a mid-month record from a precipitation-station, by telegraph if necessary. Largely for this reason and also because the securing of observations at precipitation-stations seems to be less expensive than the securing of snow-survey data, the Bureau of Reclamation has found it advisable to plan on a combination of the two methods in making its forecasts for the operation of Lake Mead and Boulder Dam.

In 1935 studies were made under the direction of E. B. Debler, Hydraulic Engineer for the Bureau of Reclamation, by one of his associates, A. F. Johnson, in an attempt to determine the most satisfactory method of making the forecasts which would be required. At that time studies were made of all the precipitation-stations which had been or were then being operated in the drainage-basin of the Colorado River above Boulder Dam. Normals were computed for all of these stations, short records compared with longer ones, and comparable 38-year normals were obtained from which the mean precipitation on each of the various component divisions of the Colorado River Basin was determined. These means were weighted according to the contribution of the various divisions to the April to July flood-runoff of the Colorado River at Boulder Dam. Curves were drawn showing the relationship between the weighted percentage of normal precipitation on the watershed and the discharge at Boulder Dam site based on a 30-year record. The precipitation used was that accumulated from October to the date of the forecast, and the inflow was from that date through the following July. Applying this method and the curves thus obtained to past years, a mean departure from the estimate of 17 per cent was obtained for the April to July runoff based on October to March precipitation.

In making these studies it was found that the higher elevations, where the snowpack remained the longest and which were the most important sources of runoff, were quite inadequately represented by precipitation-stations. It was obvious that the accuracy of the forecast could be materially increased if stations could be strategically located at some higher elevations. Additional stations were also found to be desirable at low elevations in portions of the basin where the distribution of the regular Weather Bureau stations was inadequate. Because of the limited funds available to the Weather Bureau and the regulations which had been imposed in the establishment of additional Weather Bureau stations, it was necessary for the Bureau of Reclamation to undertake the establishment and operation of 26 precipitation-gages at various locations in the Colorado River Basin in Colorado. Fortunately only a few stations were required in either Utah or Wyoming and the Weather Bureau was able to take care of the principal need in these two States. Of the 26 stations established in the winter of 1935-1936 by the Bureau of Reclamation, 23 have been operated continuously, giving what appear to be quite satisfactory records. One was moved, and, with the exception of a short break just prior to the move, has given good records. The other two have given only sketchy records because of the fact that the original observers have died or moved away, and it has been impossible as yet to find suitable persons to carry on the work.

Of the stations established, 13 were located at or near places formerly occupied by Weather Bureau stations, with the hope that the former record and that now being secured could be correlated and thus give a much longer record on which to base the normal for the station. The other 13 stations were at new locations where it was felt that records were desirable. Unfortunately, as is the usual case, it was difficult or impossible to find observers in suitable locations at the high elevations where records are so desperately needed. Only three of the stations established by the Bureau of Reclamation are at elevations over 10,000 feet. Two are on the top of passes and are cared for by persons permanently employed at these locations. The third is at the portal of a transmountain diversion-tunnel, and the observations are made by the caretaker for the irrigation company. All of the gages used are of the standard 8-inch Weather Bureau tube-type and are operated during the winter months with the receiver and measuring tube removed.

Because of the high cost of such equipment, no attempt has been made to use any of the recording gages which have been developed, though the possible necessity of branching out into this type of equipment is recognized.

Including the stations being operated by both the Weather Bureau and the Bureau of Reclamation, there are at the present time about 125 stations at which precipitation is being measured daily in the watershed of the Colorado River above Lee's Ferry. In making use of the records so obtained, for forecasting purposes, it is anticipated that probably not all will be used, but the stations will be selected in such a way that the various divisions of the basin will have comparable representation. The records of accumulated precipitation from October to the date of the forecast will be related to records of inflow to the reservoir, and the forecast based on such relationships. The judgment of the forecaster in applying such factors as depleted ground-storage, precipitation known to have occurred since the records were sent in, and other items will naturally play an important part.

Forecasting by means of a precipitation-method has been carried on in a rough way for the last three years. Some 40 selected stations covering the Upper Colorado River Basin are being used, the normals being those based on a 38-year period, as determined in the 1935 studies for the program, and the method used was that developed in these studies. Forecasts have been made about the beginning of each month from February through May, inclusive. Storage-accumulations were started in Lake Mead in February 1935 and the water-level first reached the bottom of the flood-control reserve late in June 1938. In view of the large amount of unfilled storage-capacity in this period and the lack of necessity to consider flood-control operations, no attempt was made to make a close forecast of the flood-inflow.

During the coming winter it will be necessary to thoroughly check the methods which have been used and establish a basis for utilization for forecasting of the data now available. It is not at all intended that the use of precipitation-measurements will take the place of snow-course measurements but that each method will supplement and serve as a check on the other.

Bureau of Reclamation,
Denver, Colorado

## NEED OF HIGHER-LEVEL SNOW-SURVEY COURSES IN THE COLORADO RIVER DRAINAGE-AREA OF WESTERN COLORADO

F. C. Merriell and M. C. Hinderlider

This problem is set forth in the following correspondence:

F. C. MERRIELL, Secretary, Colorado River Water-Conservation District, Grand Junction, Colorado, to Samuel B. Doten, Director, Agricultural Experiment Station, Reno, Nevada (December 3, 1938)--"From observation of local conditions and the relation of the drainage areas to western Colorado snow-courses it is felt that some research on the distribution of snow-cover is going to be necessary in western Colorado. The snow-courses as now laid out are necessarily readily accessible. In this country that means they are very close to the lower boundary of the areas which really contribute the major part of the runoff. Unfortunately, too many of these snow-courses are below the probable storage-sites, with the result that, while the snow-courses will be of great value in the prediction of runoff from the areas, the problems of storage for local use are not going to be solved by these present snow-courses. It is going to be necessary in all probability that with the present snow-courses as a base, courses of higher altitudes shall be observed for periods long enough to determine whether or not a consistent relation exists between runoff at higher altitudes and the base snow-courses now established.

"While the general problems of Colorado River runoff will be answered by the base snow-courses, it now seems probable that we shall get very little aid on our local problems from them. Has there been any such investigation of the internal distribution of snowfall on small watersheds? If so, the history of the experiment and the conclusions drawn will be of interest to us."

F. C. MERRIELL to J. E. Church, Agricultural Experiment Station, Reno, Nevada (December 8, 1938)--"As we are all agreed, the results of snow-survey work up to the present indicate that the runoff of major stream-systems can be correlated with the water-content of the snow at courses which can be considered as characteristic of the whole of the drainage-areas and each year adds to the body of record which goes to prove that very valuable correlations of this kind can be found in the West generally.

"Our problem in western Colorado seems to me to call for a more detailed investigation of snow-cover and its relation to altitude as correlated with runoff in various altitudes. The reason for this is that, while we are at present irrigating about 800,000 acres in western Colorado, only 200,000 acres are irrigated from the main streams and have anything like an adequate supply of water. The 600,000 acres irrigated by the tributaries are practically all in need of supplemental storage in reservoirs which, because of physical requirements, will in nearly every case be located near the headwaters of these streams and in most cases will be located above, or above the altitudes of, the present snow-courses.

"Since there are in most cases no records of stream-flow which can be so analyzed as to give even fair approximation as to runoff at these high altitudes, it has appealed to me that a useful result might be more quickly obtained if we could establish snow-courses in several of what were felt to be characteristic drainage-areas in which new snow-courses would be tied to the existing ones. By comparison of these higher records of snow-courses with those of the courses already established and with runoff-records which might be needed, in some cases at higher altitudes, we should presently arrive at some notion of the actual distribution of water as a function of altitude.

"I am afraid that the greatest value of such an investigation would be purely local since it seems probable that the present snow-courses and their relation to present gaging stations give the information which is needed for general forecasting of the whole water-supply. If, however, it is felt that this piecemeal investigation of a few watersheds is desirable and can be undertaken, it will give information which should be of great value locally. I realize, of course, that such an investigation will be much more expensive for the data obtained than is the work that is being done now for it will involve long trips on skis or snow-shoes to the higher snow-courses and will require also more expenses for the related stream-gaging which may be required. There will be very few instances where observers can be found for this gaging, which may, therefore, require the installation of automatic recorders.

"While this District does not have funds to provide a great contribution for any such project, we should like to contribute what money is available and any services we can render."

M. C. HINDERLIDER, State Engineer, State of Colorado, Engineering Department, Denver, Colorado, to J. E. Church (December 29, 1938)--"I am inclined to agree with the suggestions of F. C. Merriell that additional snow-courses in individual basins on the western slope of Colorado would furnish more reliable and effective data than will result from base-stations. Probably the most important problem relating to the conservation of our water-supplies in the Colorado River basin in Colorado involves the construction of a multiplicity of comparatively small storage-reservoirs, located on tributaries of the Colorado River, rather than the development of large reservoirs which, generally speaking, would be located too far down in the basin to be of the greatest benefit in the reclamation of our arable lands, or in furnishing supplemental water-supplies to existing irrigated areas.

"Likewise, the major conservation-projects, including transbasin diversions from the Colorado River basin to the eastern slope of the continental divide, involve the smaller tributaries of the Colorado River at high altitudes. It can readily be seen that a multiplicity of small courses in these high tributary areas would provide data of greater value to our State than would base snow-courses, which are so highly desirable for anticipating runoff at major gaging stations in the lower basin of the Colorado. In this connection, we have recently caused to be established a multiplicity of new gaging stations in the upper reaches of the Colorado River basin for the purposes aforementioned."

## ARIZONA VIEWPOINTS

JESSE C. WANSLEE, State Water Commissioner of Arizona, described the snow-fields in Arizona, and passed snapshots to the Conference members so as to enable them to see the snow-conditions in that territory. He remarked as to the vital necessity of snow-survey work in Arizona, both to the cattlemen and to agriculture in the State, telling of concrete examples where work of this type would have been of great benefit to the farmer. He stated that a farmer of his acquaintance, during the early spring of 1938, by his own observation, predicted that the snow-crop was a fair one and, when offered a certain sum per head for his cattle during the earlier part of the season, held off with the expectancy that the snow-crop would be sufficient to produce good pasture for his cattle and therefore increase their value materially; however, the snow-crop was fluffy, with very little water-content, and the result was that his cattle perished. He is now a politician.

MR. MARR referred Mr. Wanslee to R. L. Parshall of the United States Bureau of Agricultural Engineering, who has made studies in that territory, as the man to see for cooperative snow-work in that region.

A. R. CODD stated that the United States Weather Bureau has gone into Arizona and established a series of batteries of five snow-gages in that territory, and, for Mr. Wanslee's benefit, gave the location of each.

## IMPROVEMENT OF APPARATUS

### ANODYZING OR HARDENING THE SURFACE OF SNOW-SAMPLERS

James C. Marr

This subject has great interest because the hardening of the surface of duralumin prevents its oxidation and the unpleasant discoloration of clothes and hands. The following letter written by me under date of November 21, 1938, to S. H. McCrory, Chief, Bureau of Agricultural Engineering, United States Department of Agriculture, Washington, D. C., is therefore pertinent:

"I have your letter of November 14, 1938, describing the procedure to be followed in using the part of this year's snow-sampling equipment which has not been given the anodyzing treatment. We will distribute these special pieces of equipment to Dr. Church, R. A. Work, R. L. Parshall, and L. T. Jessup, and I will take care of one of them myself.

"I feel quite sure that one year's ordinary use of this special equipment will not permit conclusions as to utility of the anodyzing treatment. If we had some way to speed up wear, corrosion, and the effects of rough treatment, we might get a better idea. I will try to work out such a plan.

"As you know, we have had unanodyzed equipment in use since the fall of 1935. Most of those sets are still in use. The only breakage which has occurred in them has been due to the seizing of the threads. The seizing was due primarily to the fact that the threads were made to fit too tightly. Undoubtedly if the threads on those original sets had been cut to allow as much play as is provided in sets manufactured during the past two years, no trouble from seizing would have occurred. I wish to stress the point that it is absolutely necessary to have play in aluminum threads. If these threads fit as tightly as ordinary steel threads, the rubbing of the two surfaces together causes minute balls of aluminum to form which collect and cause seizing when an attempt is made to unscrew the couplings. When threads are so tight as to cause this action, they are also too tight to permit the antiseize compound to stay on the threads and, therefore, the compound is of little value when the seizing trouble is bad.

"I have made some observations regarding the anodyzing treatment. This treatment smooths the tube-surface until it is almost like velvet. Also, it makes the surface noticeably harder. In drilling holes in the equipment for spanner wrenches the bit readily takes hold on the unanodyzed surface while we have found it necessary to use a punch on the anodyzed surface in order to start the drill. Also, when it has been necessary to fit some of the older tube-sections to the new ones, we have found much more difficulty in grinding the threads together, which is due to one end of the couplings being anodyzed. In my judgment, the smoother anodyzed surface is beneficial in permitting snow-core to slip more readily through tube. The hardness is beneficial as it minimizes wear on threads. It is noticed also that the unanodyzed surface turns dark and rubs off on the hands while the anodyzed surface remains bright and does not blacken the hands.

"While I feel that the anodyzing treatment will add to the life of our snow-equipment and that it is beneficial, the cost of it may outweigh its advantage. I would like to know what it costs us to have the equipment treated in this manner. I believe the cost, rather than the reason set forth in your letter, that is, 'If the couplings are not anodyzed it will be possible to give them a somewhat tighter fit than it has been possible to do with the anodyzed treatment,' should govern whether or not the treatment should be required. In fact, we should not try to make these joints fit tighter than is the case with our 1938 equipment. While there is a good bit of play in the threads of the equipment manufactured during the past two years, it does not result in a loose-fitting joint. When these joints are completely made up with the shoulders together, they are quite rigid."

U. S. Bureau of Agricultural Engineering,
Boise, Idaho

## IMPROVEMENT IN MOUNT ROSE SPRING BALANCE; "TICKLING" CORKY SNOW

Fred H. Paget

### (a) Mount Rose spring balance

At this time I have merely two rather minor items which, however, I should like to bring up for discussion.

The first of these is the matter of slight improvements that it appears could be made to advantage in the Mount Rose scales. Those of you who use the Federal tubular scales exclusively in your work will not be especially interested, but it is important to us here in California, where, out of some 70 sets of scales in use in the field by the California Cooperative Snow-Surveys, over half of them are of the Mount Rose type.

To insure the accuracy of our snow-measurements, we try to test out the accuracy of each set of scales each year. If the scales are wrong, the measurements will be wrong even though the measurements are made by the most conscientious man in the country.

The tubular scales, some of which we started to use for the first time two winters ago, have never given us any trouble and this summer every one of those tested, checked out almost to the dot, with errors not exceeding one-fourth of one per cent.

In passing, I might say, however, that in so far as California is concerned, the so-called 20-foot-capacity scales do not always have 20-foot capacity. The weight of the 20-foot empty tube with the driving wrench attached gives an initial reading on these scales of about 67 inches of water. As the graduation of these scales ends at 140 inches, that leaves only 73 inches for the snow-core, which assuming a nominal density of 45 per cent will allow measuring a snowpack only 162 inches deep, that is, only 13.5 feet. Last winter, one crew using this equipment got into snow 16.5 feet deep at 45 per cent density, which far overran the graduation of the scales. (See test by John T. Ryan described following paper by W. Poulsen.)

However, in so far as holding their adjustment, the tubular scales, with the advantage of youth on their side, have to date been just about perfect. Most of our Mount Rose scales have been in the field since 1929 and none of them tests out perfectly any more. The best of them average errors of from one to two per cent and a couple of them, when tested this summer, showed errors of four or five inches in 100, while on two sets, due to friction in the scales caused by spring torque, the needle for any given load would come to rest almost any place within a range of five inches each side of the correct reading.

In order to get an outside viewpoint on repairing and adjusting these scales, several of them were taken to a firm in Sacramento, which has the agency for an internationally known scale-manufacturer. This firm put them in good shape and made a few suggestions, as follows:

(1) In all cases where the rack has not been provided with a spring to hold the rack in close contact with the rotating pinion actuating the indicator-needle, such a spring should be installed.
(2) The rack and pinion should be made of durable metal. Bronze or brass should always be used in preference to steel.
(3) The rack should be made thicker. This would mean a wider surface on the teeth in contact with the pinion and would result in longer life.
(4) (I think this one is the most important of the lot.) The top of each spring should be connected to the head frame of the scales with a small swivel in place of the positive connection now in use. With the present arrangement, any adjustments are limited to multiples of half turns and any correction less than one-half turn can only be taken care of by grinding the outside of the spring, which, although a common practice, is not one to be recommended. With the swivels, fine adjustments of the springs would be possible without throwing any torque on the hanging parts which might cause friction and inaccuracy.

### (b) "Tickling" corky snow

The second matter concerns a method (which was new to us) of taking samples where a certain difficult type of snowpack was encountered.

The snowpack of the 1937-38 winter was peculiar in that its accumulation did not really begin until the middle of January and then for several weeks snow fell every day, piling up to great depths. As a result of the heavy weight of the deep snowpack, the lower layers were consolidated while still in the light fluffy state. After the storm, the alternate thawing and freezing of the top layers changed the crystalline structure of the snow, making it coarser to a considerable depth, but the lower layers were too far down to be affected, so that on April 1, when the snow-measurements were made, these lower layers were still in the same fluffy state as when laid down.

This packed layer of fluffy snow (the boys called it "Corky snow") caused trouble to the snow-surveyors all through the State. At this layer, the throat of the cutter invariably became solidly plugged and any effort to drive the tube by applying more pressure and rotating the tube merely pushed the plugged tube down through the snow without getting any additional core.

Because of this, most of the men were forced to take their samples in two sections; the first one down to this troublesome layer, and the second one from the top of the layer down to the ground.

On one of the survey-crews last year was a young engineer for the telephone company, who had taken his vacation at that time so that he could go into the hills with a snow-survey crew for the trip. After watching for a while the trouble the old-timers were having trying to get a good sample, he asked to be allowed to try his luck at making a measurement to see if he could do any better. He tried his own method and had 100 per cent success, being able to get his core from the top down through the troublesome layer to the earth below in one try. It was not an accident, as he did it over and over again, and when the others adopted his tactics they too had no trouble in taking their samples in one piece.

His method was simply this--to allow the tube to penetrate more or less under its own weight with no other downward pressure applied, and the rotation of the tube was limited to quarter or half turns back and forth instead of round and round to the right as has been our usual practice.

Through 15 feet of snow with a troublesome layer of corky snow about two feet thick, this method generally required about five minutes to patiently allow the tube to work its way through, but, even at that, time was saved over the less desirable two-section method which was the only other way that a sample could be obtained.

This method has been named "tickling the tube through" and, although I don't advocate that our snow-surveyors should in all cases become "ticklers," I did want to hand this method on to you for what it may be worth, should you or your men some day run into a similar situation.

California State Division of Water Resources,
Sacramento, California

## METHOD OF APPLYING BAKELITE TO SNOW-SAMPLER

Wayne Poulsen

The bakelite employed is commercially known as Risch-Rasch used as a running base on skis. The bakelite was thinned with equal parts of acetone. Application with a rag on the end of a fishing rod did not prove very satisfactory but had to do for lack of a spray-gun or dipping apparatus. Three to four coats of Risch-Rasch should be applied at 12-hour intervals. Rubbing down with steel wool before each coat improves the finish.

This method, when employed on the running surface of wood and metal of skis, has been known to last as long as 40 skiing days. The Risch-Rasch will not chip off nor crack if applied properly. From all indications several coats should be sufficient to last a snow-sampler several years.

No attempt has been made to remove the Risch-Rasch yet, but it should respond to a coat of a liquid known commercially as "Fortus" which is specially produced to remove ski-lacquers.

During limited experiments, the sampler has not clogged once. Snows of various textures were tried. "Fortus" does not injure the wood or metal as tried on skis. Whether or not "Fortus" will injure the duralumin sampler remains to be seen.

University of Nevada Ski Team,
Reno, Nevada

The above discussions were supplemented after the meeting by the following matters contained in a letter by Mr. Paget to Dr. Church and a careful test by John T. Ryan of the tubular balance to determine its total capacity.

## PARAFFIN VERSUS ENAMEL; OPTIMUM NUMBER OF SAMPLING POINTS; IMPROVEMENT OF TUBULAR BALANCE

Fred H. Paget

### (a) Paraffin versus enamel

With reference to the use of paraffin for the duralumin tubes, Wayne Paulsen has referred to a new base-varnish for skis developed in South America. This varnish has a bakelite base and it goes under the name of "Risch-Rasch." Paulsen stated that, in his experiments with it as a coating for the duralumin tubes, he was having trouble getting a smooth finish on the inside. It is suggested that the plunger-method be used as described above in "California Cooperative Snow-Surveys: Directions, suggestions, and hints for snow-surveyors."

However, there is one drawback to coating the duralumin tubes with a hard varnish. No matter what kind of a coating is put on, in my experience it wears out in spots after one or two year's use, and has to be retouched. After a few retouching jobs are done, the tube gets so rough inside that the whole old inside coating has to be entirely removed and a fresh start made. On our steel tubes we use shellac--sometimes valspar varnish. After several retouching jobs, when the insides get so rough that a rejuvenation is needed, we clean out the layers of old hardened coating either by immersing the tube bodily in a hot caustic solution--commercially called "Oakite"--which eats it out, or else we use a wire flue-brush on a ramrod, rotated by a small electric motor, which cuts out the old varnish and shines and polishes the inside of the tube at the same time. On account of the softness of the duralumin, neither of these methods of removal could be used. The only way would be to take the old coating off by immersing for a long time in alcohol or some other paint-remover.

As this last method would take quite a while and several immersions before all the old shellac would be entirely removed, in California we continue to standardize on the use of paraffin coating for the duralumin tubes. It is found that with ordinary care a set of tubes, carefully coated with paraffin, will last through one season's wear and the paraffin seems to be as good a preventive of sticking core as any other coating.

It has been stated as an argument against the use of paraffin that sometimes, during a snow-patrol involving measurements at many snow-courses where a lot of measurements have to be made at each course, the paraffin wears off before all the samples can be taken. In cases like this a spare lower joint could be carried along. The weight of an extra joint is negligible and it is in general the bottom joint that wears out, while the others are still in good shape.

### (b) Optimum number of sampling points

In passing, this brings up the subject of number of sampling points. George Devore's thesis-work, as well as investigations made by us for separate California courses, indicate that in many cases a lot of sampling points can be cut out without altering the resultant measurement of mean water-content at the course. Devore, I think, found that 16 points were plenty. In the Kings River watershed--and on the Kings River our forecasts are just as accurate as on any other stream--most of the snow-courses have only six or seven sampling points each. Fewer samples would of course not be so hard on the tube-coating, but the big argument in favor of fewer samples is the conservation of time and labor often expended needlessly where snow-courses have, through lack of knowledge of local snow-conditions, been laid out with several times the number of samples necessary.

### (c) Tubular balances

How about recommending that the graduations on the 20-foot-capacity scales be graduated beyond the 140 mark as at present? There is sufficient room on the barrel of the scales for further graduation, provided, of course, that the capacity of the scales for accurate measurements extends beyond the present graduations. With heavy snow, these scales, as they are now, will not handle a depth of 20 feet.

It has been suggested by one of our cooperating field-men that the scales have three lines of graduations on the inside barrel at 120° of each other. With only the single set of graduations as at present, it happens very frequently that the line of graduation during observation comes on the side of the scales away from the observer and cannot be read; the suggestion to have three lines of graduations should therefore be helpful.

California State Division of Water Resources,
Sacramento, California

JOHN T. RYAN, Superintendent of Shops at the University of Nevada, has made the suggested test (see Fig. 1) of the tubular scale and found that its capacity can be increased from 140 to 185 inches and even to 220 inches with no apparent loss in accuracy. This will merely require the extension of the graduations to the end of the tube. This additional capacity of 45 inches of water-content will add, at 55 per cent density, 82 inches to the usable length of the sampler, or a total of 20.3 feet. The use of the entire length of the tube for graduations will give a full foot or more additional. PHILIP S. COWGILL suggests that larger figures be stamped on the sampler tube itself.

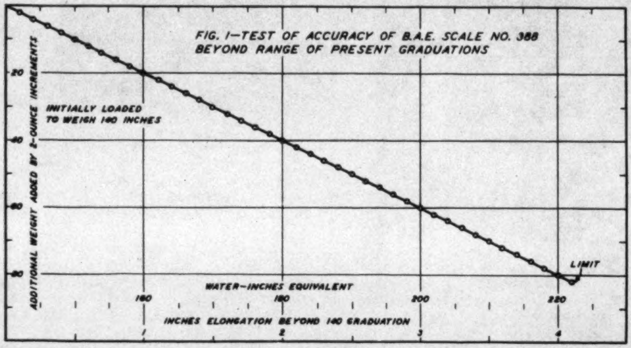


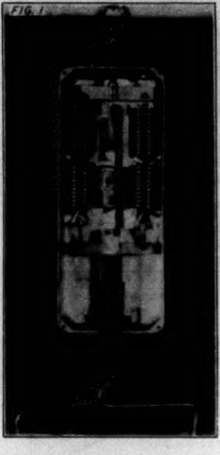
FIG. 1—TEST OF ACCURACY OF B.A.E. SCALE NO. 388 BEYOND RANGE OF PRESENT GRADUATIONS

## APPLYING THE CHATILLON ISO-ELASTIC SPRINGS TO THE MOUNT ROSE SPRING BALANCE

### Carl Elges

The maximum success of spring scales, though used with a relatively high degree of usefulness for centuries, has been hindered by the presence of errors resulting from the following inherent difficulties:

(1) Changes in stiffness of spring, that is, in modulus of elasticity, with changes in temperature
(2) Differential variations in length of the spring itself and the attached parts due to expansion and contraction with temperature
(3) "Creep" of the metal of the spring under stresses well within the elastic limit followed generally by a gradual elastic recovery after the load has been removed
(4) Hysteresis in the metal manifested by failure of the spring to follow the same load deflection-curve on increasing and on decreasing loads; this makes itself evident in the form of "back error" in the scale
(5) Slight deviations from straight-line characteristics in the inherent elastic stress-strain curve of the material
(6) Deviation from straight-line characteristics of the load deflection-curve due to changes in pitch-angle, radius of coil, etc., of the spring itself as it changes in length under load
(7) Deviations from proper shape and form in the transmitting machinery between the weighing spring and the indicating mechanism due to improper design
(8) Further errors resulting from slight inaccuracies in workmanship in the transmitting machinery and in the indicating dial itself



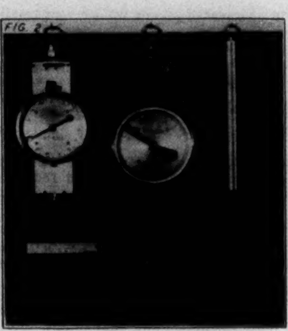


*FIG. 1—CHATILLON SCALE WITH THE FRONT COVER REMOVED SHOWING THE ISO-ELASTIC SPRINGS*

*FIG. 2—ROSE SPRING-BALANCE, CHATILLON MODEL, AND THE BUREAU OF AGRICULTURAL ENGINEERING SCALE (LEFT TO RIGHT)*

Actually most of these errors are relatively small and for years the better grades of spring scales have been considered as giving satisfactory service. However, John Chatillon and Sons, noted for the manufacture of spring scales, conducted an investigation and developed what they call an "Iso-Elastic" spring. As a result of this investigation the above errors have been eliminated as follows:

(1) Temperature-changes of the first type have been eliminated by the use of an alloy of a modified Elinvar type, which has been named because of its properties "Iso-Elastic Metal" with modulus of elasticity constant at approximately 9,000,000 pounds per square inch in torsion over relatively wide ranges of temperature. By changing the chemical composition, the position of this range of constancy can be shifted higher and lower to suit special conditions, if necessary. Temperature-errors of the second type are negligible in amount, but can, if desired, be completely eliminated by proper choice of the metals used in the frame and transmitting mechanism.

(2) Creep and hysteresis errors have been reduced to extremely small proportions while at the same time the allowable working stresses have been increased by adding 0.4 to 0.8 per cent Mn and 0.5 to 1.5 per cent Mo to the 36 per cent Ni, 8 per cent Cr Elinvar alloy, by care in manufacturing, and by making use of an unusually high degree of cold work, followed by a low to moderate temperature heat-treatment. At stress of 60,000 pounds per square inch, creep has been reduced to less than 0.02 per cent of the deflection. The accompanying "back error" or hysteresis is not over 0.02 to 0.04 per cent of the full-load deflection.

(3) By using wire of rectangular cross-section, coiled with the long axis of the wire parallel to the axis of the helix, the spring itself has been given an inherent straight-line relationship between load and deflection. This has also involved the use of special precautions in manufacture as well.

(4) Secondary difficulties due to binding of pivots resulting from coiling or uncoiling of the springs under load changes have been eliminated by use in tandem of a right-hand and left-hand coil-spring.

The resulting springs used in a Chatillon spring scale called an "Iso-Seal" scale give an accuracy of 99.92 per cent.

At the request of the Department of Meteorology, Nevada Agricultural Experiment Station, John Chatillon and Sons made up a scale patterned after the Mount Rose spring balance but incorporating the Iso-Elastic springs. Figures 1 and 2 show the Chatillon scale between the Mount Rose scale and the Bureau of Agricultural Engineering Scale, and a close-up view of the inside of the new scale. As can be seen from the Figures, the Chatillon scale is too large for snow-survey usage. It weighs 6 pounds 5 ounces, whereas the Mount Rose scale weighs 2 pounds 12 ounces and the Bureau of Agricultural Engineering scale but 1 pound 1 ounce. To obtain the increased accuracy, the spring was materially increased in size and cannot be satisfactorily adopted for snow-surveys because of the size and weight of the case necessary to enclose the springs. Perhaps with further development it will be possible to reduce the size of the springs so that a smaller scale will result.

(Complete information regarding the Iso-Elastic springs is given in a paper by M. F. Sayre and A. V. de Forest presented at the annual meeting of the American Society of Mechanical Engineers, New York, N.Y., December 3 to 6, 1934.)

Nevada Agricultural Experiment Station,
Reno, Nevada

DR. CHURCH commented on the Iso-Elastic springs, stating that, since an accuracy of 99.92 per cent is claimed for the scale as developed by John Chatillon and Sons, it would be an excellent scale for measuring the evaporation of snow and ice where the utmost accuracy is desired. Furthermore, the spring scale is far more convenient to use than the steelyard for this purpose.

## SHIELDED STORAGE PRECIPITATION-GAGES

Ashton R. Codd

The United States Weather Bureau has for many years rendered an important public service in measuring the precipitation throughout the country and publishing the data for general use. During recent years, because of the rapid expansion in the field of applied hydrology, the Bureau has been called upon to improve its method of measuring snowfall, and to expand its services into new fields.

J. Cecil Alter, Meteorologist in charge of the Weather Bureau office at Salt Lake City, Utah, began experimenting with storage-gages and shielded gages in 1909. His work has resulted in the present design of the shielded storage precipitation-gage which made its debut in the snowfields of the Western States in 1937. The principal reason which prompted Mr. Alter to continue his work with the shielded storage-gages was that several key precipitation-stations in Utah were attended from May to October, producing fine records, but because of isolation in winter the stations would be abandoned from November to April. As these were the months of heaviest precipitation, a storage-type of gage was required to hold the catch until it could be measured. At regular cooperative stations, especially in windy locations, the measurement of snowfall and its water-equivalent by ordinary means has been subject to criticism, and especially where snow-depth alone became the basis of the estimate.

In the operation of the storage-gages in use at the present time, a small quantity of concentrated anti-freeze solution is put into an 8-inch rain-gage receiver, covered with a film of light oil, and weighed. The gage-can is exposed as any other rain-gage, and weighed daily, or after precipitation has occurred. The difference between weights converted to inches of water gives the precipitation for the period between weighings. Should the observer move to lower altitudes, the gage could be revisited and weighed at weekly or monthly intervals.

In Figure 1 is shown a standard shielded storage precipitation-gage, 8-foot support. The framework is constructed of galvanized angle-iron 1-1/2 by 1-1/2 by 1/8 inch, braced by galvanized band-iron 1 by 1/8 inch, the structure being held together with galvanized bolts 1 by 3/8 inch.

The shield is made up of strips of No. 20 galvanized sheet-iron hung on a 3/8-inch round rod bent into a 36-inch diameter circle, clamped together with a 1/4-inch cable clamp. The shield-leaves are held in position by chain and wire. The gage-can is constructed of No. 26 gage galvanized sheet-iron, eight inches in diameter and 23-1/2 inches deep. This can is held in the center of the shield by a top collar, yoke, and a bottom collar. The yoke is free to turn when the can is swung to the front, thus making it possible to remove the gage-can from beneath the shield when the observer is ready to weigh the precipitation. A bracket attached to the left support is used to hang the scales and can while weighing.

The purpose of the shield around the gage-can is to minimize the effect of updrafts that ordinarily disrupt the catch. The shield-leaves are hung loosely on the shield-ring, and are free to swing in the wind, although kept in place by a lower chain. The movement of the leaves also serves the purpose of dislodging any snow that may accumulate on them. The relation of the

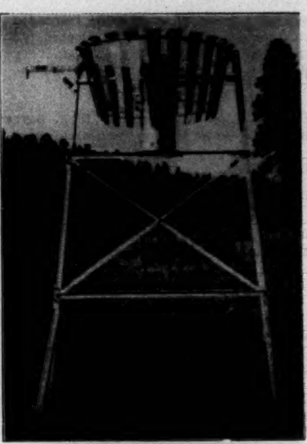


FIG. 1—STANDARD SHIELDED PRECIPITATION-GAGE WITH 8-FOOT SUPPORT

diameter of the shield to the diameter of the gage-can has been established through the years of experimenting by Mr. Alter.

The gage-frames have been built of various heights, depending on the depth of snow expected at the station.

A very satisfactory method of erecting these gages in the field is to set the frames in trenches approximately 18 inches deep. The frames are then leveled and plumbed, a few large rocks placed on the foot pieces, and the earth tamped back into place. No concrete foundation or mud-sills are necessary.

The frame can be remodeled very easily to accommodate an automatic-recording rain-gage. This has been done at several stations and has proven to be very satisfactory. The two-leg frame five feet high is recommended for low-altitude stations, but where the gage must be raised higher than five feet it is recommended that a tower-type frame be used in order to assure stability to the recording mechanism.

The cost of the two-leg gage-frame is largely dependent on the number purchased. If a single gage is purchased, the present price is approximately $3 to $3.50 per foot of height. If five or more are purchased, the price is reduced to about $2 per foot of height. The four-leg tower-type frame is relatively more expensive, being approximately $4 per foot of height.

Freezing is prevented in the storage-gages by the use of a 33.4 per cent solution of calcium chloride, obtained by combining 1-1/2 pounds of flake calcium chloride with two pounds of water. The salt must be thoroughly dissolved before the solution is ready for use. The solution is well above the eutectic point, so that ample allowance for dilution before freezing is provided even at exceptionally low temperatures.

Experiments were made with various percentages of solutions of calcium chloride to determine the reactions of the solution at sub-zero temperatures. Solutions of various strength were exposed to temperatures of -65° F for one and one-half hours. The weak solutions, of course, froze slightly. In no case was a hard crust or cake of ice formed that would burst the cans.

The oil used in the gage to prevent evaporation and absorption is a good grade of turbine oil, which will not evaporate in summer or become thick under winter temperatures. In cases where ice-formation has been noticed in the gages at Salt Lake City, the oil was above the ice.

The galvanized sheet-iron gage-cans are painted on the inside with a protective coating of paint to insure against any possible corrosive action of the salt solution.

It has been the general practice to equip each mountain snowfall-station with five shielded storage precipitation-gages. The gages are placed in an approximate square 300 to 400 feet on a side, with one gage in the center. This arrangement gives a real significance to the record and overcomes the criticism of the point-sample provided by a single snow-stake. A mean catch of the five gages is taken as the precipitation-depth for the station. The deviation in catch of any one gage from the mean catch of the five gages is relatively small. Data collected from the stations in New Mexico, Utah, and Yellowstone Park during the season 1937-38 showed that at only one station did the general deviation, plus or minus, amount to much more than one-tenth of an inch. The data also showed that if a gage caught more than the average, or its deviation was in the plus direction, that gage generally maintained this characteristic throughout the season. In no case did the amount of deviation show a relation to the amount of catch.

During the fall of 1937 the Weather Bureau began its expansion of mountain snowfall-stations by equipping already-established stations with shielded gages and also establishing new stations at desirable locations. Twenty stations were equipped during the season--four stations in Utah, three in Yellowstone Park, and 13 in New Mexico. During the fall of 1938, 27 stations were equipped and placed in operation--11 stations in Utah, nine in Arizona, one in New Mexico, three in southern Colorado, two in Montana, and one at Field, British Columbia, on the Columbia River.

U. S. Weather Bureau,
501 Federal Building,
Salt Lake City, Utah

## DISCUSSION

MR. CODD displayed a miniature model of the snow-gage. He stated that the scales at the present time are read in pounds and ounces, and thence reduced to depth in inches of water; however, scales can be fabricated and correlated to read direct in inches of water.

MR. MARR stated that these gages could be checked with the snow-courses maintained by the Division of Agricultural Engineering where the Division maintains a course that is located parallel to the location of the snow-gage measurement-station.

Discussion followed by FRED H. PAGET and MR. CODD relative to the mixture of the solution and the snow. MR. CODD stated that the snow, upon entering the snow-gage, turns into a solution. A battery of five gages is placed in a snow-field within a radius of approximately 400 feet, forming two rows, one row being perpendicular to the other, forming a cross. These gages will be a great help in snow-survey work. At the present time, gages are not being installed where an observer is not available.

Discussion followed by MR. PAGET and MR. CODD as to whether these snow-gages will supplant snow-surveys. MR. CODD stated that he was unable to answer this question at this time; however, he felt that these gages will be able to fill out the gap.

Discussion followed by J. E. PHILLIPS and MR. CODD as to whether any of these gages were located in close proximity to a snow-survey course. MR. CODD, in answering this question, stated that there are some in Montana, within close proximity to the snow-courses maintained by the Bureau of Agricultural Engineering of the United States Department of Agriculture.

Discussion followed by W. A. LANG and MR. CODD relative to the time-interval of reading the gages and also the cost of establishing these gages. MR. CODD stated that these gages were read by storm-period intervals, except where the reading was desirable daily as in conjunction with a regular United States Weather Bureau Station; however, these gages can be read monthly, seasonally, or periodically after each storm. The cost of establishing these gages is approximately $2 per vertical foot.

## SNOW-SPORTS

### SNOW-SURFACES IN THE HIGH SIERRAS FOR SKIING PURPOSES

Wayne Poulsen

The amateur skier who frequents the Sierra ski-fields is generally one who has had to acquire his knowledge of snowcraft during brief holidays. As a rule, these vacations occur at wide intervals during the ski-season, sometimes under unfavorable conditions. As such, they can not give him the necessary experience or knowledge to judge ski-fields.

We are more concerned here with the practical aspect of snow-surfaces for winter-sports purposes. To date, the ski-enthusiast of the Sierras has been under severe handicaps. Since the average skier has to travel long distances to ski, he seldom knows in advance what the condition of the snow will be. Not infrequently, his week-end in the ski-fields is spoiled by poor snow- or weather-conditions with a resultant loss of time, money, and energy expended.

I will attempt here to show the changes in snow-texture which occur during the entire ski-season as they affect skiing conditions. This is based upon personal observations covering a period of ten years and most of the snow-fields of the high Sierras. Last winter I had the opportunity to observe and record snow-conditions as they affected skiing throughout the entire season. This was done for the sole purpose of determining the location of a winter-sports plant in the Mount Rose - Lake Tahoe area. First, I will try to set down a standardized classification of snow-textures which can be used for practical purposes in skiing by the average enthusiast.

The sole instruments which I have used in these observations are a thermograph and a Mount Rose snow-sampler. My skis and their reactions to these surfaces have been my main basis for judgment.

Snow-surfaces have been classified many times. Some have been too simple, some too cumbersome. Too simple a classification is obviously of little value. Differentiations, if carried too far or explained in technical terms with hair-splitting definitions, are of little practical value to the average skier and are unwieldy at best.

Winter resorts and other agencies have attempted to give out information on the condition of snow-fields to the mass of skiers. In general, I feel they have failed miserably. The only real information which they have been able to give about the snow has been its depth. This can be attributed to several causes: (1) The observers are usually untrained; (2) reports have a tendency to be too optimistic; (3) snow-conditions change suddenly; (4) there is usually a time-lag between the observation and the announcement.

As a result, the average enthusiast can only be sure of the approximate depth of the snow at his particular destination. He knows nothing of the quality of the snow.

Standardization of terms used in classification can go a long way in correcting these evils. There is a definite need for a simple, universal classification of surfaces. Standard practical terms are necessary for use in description, waxing, and ordinary conversation on the subject. There have been perhaps as many classifications of snow-surfaces as there are skiers. Seligman has, of course, set forth the primary types and their variations. Lunn and Canfield have also contributed. But skiers are not yet agreed on any one set of terms. Local conditions affect these perhaps more than any other factor. Conditions prevalent over regions, however, seem fairly constant. Thus snow-surfaces in the Sierras may differ generally from those in the Adirondacks. On this account it is difficult to put down a set of terms which could be universally used.

I propose the following terms to be used in describing the snow-textures in the Sierra Nevada Mountains for practical purposes in skiing nomenclature. This classification is based entirely upon the reaction of the skis against the surface of the snows.

(1) Powder-snow--Dry, cold, powder-snow, including surface hoar, fog deposits, newly fallen corn-snow, tapioca-snow, wild dry snow, and snows of similar textures. This type may be indicated as either new or old. The main characteristic of powder-snow is that it is cold and offers little resistance to lateral movements of the ski. It is prevalent over large areas only when the temperature is below 32° F and has fallen during a complete calm. The depth should be indicated in describing soft snows, as resistance to the surface of the ski is generally in direct proportion to its depth. The base should also be indicated. For example, "Six inches new powder-snow on breakable crust."

(2) Wet snow--Balling, thawing, soggy, slushy snow, newly fallen or old snow which has become wet through change of temperature or has simply fallen in a wet form. The causes might also be light rain, warm wind, or damp air. Snow that is in the process of firnification before the grains become loose and separate. The main characteristic is the fact that it is wet and offers a definite resistance to lateral movements of the ski.

(3) Heavy snow--Any snow, wet or dry, which has settled so as to be heavy, fallen wet and heavy, or is so toughened by freezing or wind that it offers great resistance to lateral movements of the skis.

(4) Spring snow--That snow which is the product of the firnification-process, loosely grained, either in a new or advanced state, when the cement between the grains has melted or is in the process of being melted--the firn snow of Seligman, either wet or in a dry granular state--the "Kornschnee" of Seligman in the Alps. The main characteristic is the fact that the snow is granular, very fast, and offers little resistance to lateral movements of the ski.

(5) Breakable crust--Snow that has a crust on its surface which will not support the weight of a skier. A condition when the ski will break through the crust when weighted. This condition offers very poor skiing since the skier is continually breaking through the crust.

(6) Glazed crust--A light, transparent film on top of the snow, which usually forms on top of soft snow or a solid pack. It frequently occurs on slopes exposed to the wind during periods of good weather by freezing at night and thawing slightly during the day. It does not affect lateral movements of the ski to any noticeable degree. It is characterized by a small air-space immediately under the film. It is fast and easy to turn in. This should, perhaps, be classified as a spring snow, since it reacts to the ski in much the same way.

(7) Unbreakable crust--May be formed by wind, Sun, rain, or any other element. The main characteristic is usually iciness, and the fact that it will support the weight of the skier. This includes marble crust and the like. This surface offers no resistance to lateral movements which makes it very hard to ski upon. It furnishes no lateral stability whatsoever.

(8) Packed snow--Snow which has become hard-packed either by wind and Sun, or the continual use of skiers of the various trails and practice slopes.

(9) Pitted snow--This is self-explanatory. It includes both perforated and foam crusts, the most advanced form, of course, being Nieve Penitente, due to prolonged ablative effects. This obviously offers very poor skiing since it is so rough. When this is in an advanced stage it is impossible to turn against the grain of the snow. This is due to the fact that all of the pits and perforations point south--into the Sun, and into the wind--usually west in the Sierras.

(10) Erosion forms--Such as skavler, wind slab, cushions, scoops, cornices, etc., are self-explanatory and need only be mentioned here from the practical viewpoint.

I believe the foregoing will give us a group of workable definitions which will serve the average skier who frequents the Sierra snow-fields.

It has been my observation that snow-conditions in general throughout the Sierras depend upon two factors: (1) Exposure and direction of slope, and (2) elevation.

In regard to the direction of the slopes several rules which hold generally true can be put forth.

(1) North, northeast, or east slopes have snow longer and the condition of the snow is more favorable for skiing during the greater part of the season.

(2) West slopes generally have the worst conditions throughout the season. This is true during the greater part of the season. There are certain exceptions due to unusual protection, early spring snow, and weather-conditions.

(3) South slopes have shorter seasons than north, east, and west slopes, but frequently they have more favorable ski-conditions. This is especially true at high altitudes.

Altitude also affects the ski-season and the condition of the snow.

(1) There is more snow and a longer season at high altitudes.

(2) There are better snow-conditions at certain periods at high altitudes, that is, early winter (October 1 to January 1) and late spring (April 1 to July 1).

Thus we see that if the skier goes on a tour several miles he will encounter a great variety of snow-conditions. This is especially true of slopes of various exposures, and different elevations are included. This fact calls for an intimate knowledge of snow-surfaces since they require different ski-techniques as well as waxes.

As an example of this varying condition, due to change in altitudes and exposure, I will cite a case which occurred last winter. These conditions prevailed for three weeks during which time there was no snowfall.

We started from our cabin, at an elevation of 9500 feet, which was located in a small glacial cirque on the north side of the ridge. [For views of this area, see Trans. Amer. Geophys. Union 1938, pp. 733-735.] The temperature at the cabin was 36° at 10 a.m. We climbed to the top of the ridge (Rifle Peak), 9700 feet. The snow-condition was perfect for skiing on the north side (10 inches of powder-snow on a firm base). The very top of the ridge had an unbreakable wind-crust and skavler. Dropping down 500 feet on the south slope, which was very open, we encountered firn snow. The Sun had just begun to warm the snow-surface, melting the cement between the grains of snow. Here we had perfect spring skiing. Now, cutting diagonally across the ridge to the east and up to the top again, we encountered a great variety of snow-conditions. The ridges extending south had powder-snow on their east faces and wind-crust on their west faces. The great open south slopes (except in the wooded portions) had spring snow ideal for skiing, very fast and very easy to turn in. The top of the ridge on the south side had wind-slab, skavler, and wind-crust. Cornices were found all along the ridge on the north side. Dropping over to the north side of the ridge where there are several small, well-protected glacial cirques, we found perfect powder, except on the west faces where wind-erosion was in evidence. One great open exposed north slope had wind-slab. Dropping back over to the south side of the ridge, essentially the same conditions prevailed as farther back along the ridge except for erosion-forms. Here one great west slope in particular had enormous wind-scoops and cushions which were formed behind and around trees and rocks all pointing east and uphill.

Directly over the ridge on the north side there is a series of glacial cirques. All of the north, northeast, and east slopes ending in these cirques held powder-snow, its perfection varying in proportion to its exposure. The stream flowing through these cirques to the meadow had caused surface hoar which varied in depth up to four inches. The south slopes of these cirques, being well protected from the wind, had firn-snow. Thus the two perfect snows of the skier were present in a very small area, although differing widely in their type and origin, one being true snow, the other being a product of the firnification-process, on old snow.

Continuing eastward to a higher more exposed meadow, we encountered wind and sun crust, plowshares, and bare patches. This meadow had little protection, sloped off toward southeast, and consequently offered very poor skiing conditions.

Passing through the meadow, we found crusts and wind-waves on the east slope. One spot in particular had waves as high as 10 inches and some measured 10 to 20 feet from crest to crest. We observed this one series throughout the season. Later they grew to heights of four feet. I believe this was due at least partially to cushioning and scooping, however.

Passing over the next ridge to the north, we found powder-snow on all of the north slopes; wind-crust, cushions, and even large bare patches, on the west slopes. The east slopes were in a variable state of powder and breakable crust. The south slopes had a very shallow layer of pitted wet snow. These conditions held generally down as far as 7500 feet. At this elevation, the only snow present was on the north and east slopes. It was either unbreakable crust or in a variable state ranging from breakable crust to wet pitted snow.

I do not feel that depth of the snow is so very important to the average skier who frequents the high Sierras, unless he is determined to visit one particular area. That this should be true is due to the fact that the great number of skiers travel from a no-snow area up into the Sierras until they have reached an altitude where there is sufficient snow. During severe or prolonged storms which characterize our ski-season, the snow-line moves down in proportion to the intensity of the storm. During this time, the snow is frequently so heavy at the popular ski-centers as to be practically unskiable. But at the lower elevation where a smaller amount of snow has fallen, the snow is in fairly good condition for skiing purposes. This holds generally true during even the most severe storms. Then, unless the individual is accustomed or determined to visit some particular area at a high elevation, he can be reasonably certain of fairly good snow-conditions at some lower point. He will not have to wait for the snow to settle before he can obtain good skiing.

However, in the higher areas, storms are sometimes so heavy and prolonged that touring may be an impossibility for several days. This is especially true if there are great falls of heavy wet snows, a condition which frequently occurs. In general, the skier can expect reasonably good skiing within two or three days after a heavy storm.

Of course, at centers where there are a great many persons out skiing at once on particular slopes, these slopes will be kept packed and in good condition for "meadow" skiing by the skiers themselves. In this case the snow is conditioned as it falls and works out in remedying even the worst crusts or other conditions which occur throughout the season. Heavy snows in these cases handicap the skiers only during the first part of the conditioning process.

During the early part of the season, and, indeed, at any time during the season, rain sometimes falls in the high Sierras instead of snow. If the rain is heavy it may wash all the snow off the popular ski-areas or completely ruin the surface of the snow until the next snowfall. The elevation of the ski-fields in this case plays a large part. As a general rule, during the wettest seasons it will not rain above 6500 feet. This is especially true from December to the first of April. However, occasional storms will wash all of the snow away as high as 10,000 feet. Rain will not only cause poor skiing conditions, but will usually put ski-fields in a very dangerous condition.

As an illustration, such a condition occurred on December 9, 1937, while Halvor Mikkelsen and myself were stationed at Rifle Peak. At 8 a.m., temperature 26°, heavy snow started falling, driven by a strong wind which had been blowing all night. The snow continued steadily all day with the wind lessening and the temperature rising. At 5 p.m. the snow became very wet and heavy with the temperature at 33°. At 9 p.m. the snow changed to rain with an increasing wind, temperature at 36°. It rained all night with a heavy wind, which came from the west and southwest during the entire storm. The wind and rain continued heavily all day and night of December 10. On December 11 the rain changed to snow at 8 a.m. with a little let-up of wind. It changed back to rain, however, after an hour. The temperature dropped from 36° to 34° when it snowed, but rose to 36° when it changed back to rain. The rain changed back to snow at 11:30 a.m. and continued all day with a decreasing wind. The snow was very wet and heavy, falling at temperatures ranging from 30° to 35°. After snowing all night, a new cover of only 10 inches had fallen on the old pack which had been reduced from five to two feet. The new cover was very heavy and wet, making very difficult skiing conditions.

At 10 a.m., December 11, when we were certain that it would continue to snow, we started on skis for Iceland down Grey Creek Canyon some ten miles distant on the Truckee River. This meant a drop of about 4500 feet in elevation. Immediately we found that the snow was in a very dangerous condition to ski upon. Wet-snow avalanches had occurred on all sides of the canyon. Although the walls of the canyon were very steep, they had a great deal of natural anchorage and usually were very safe under most unusual conditions. Although we proceeded with the utmost caution, and skied several hundred feet apart, our weight on the new snow caused three big slides and several smaller ones. We regarded ourselves as being very fortunate in not being caught in any of them.

The rain had washed most of the snow off below 6500 feet in this particular area. This was the time of the flood in the Truckee River Canyon and the Sacramento Valley.

The snow which followed this rain-storm left an average cover of four feet, the surface being a fine powder which made very good skiing conditions. At this time, the snow was completely washed off most of the big ski-centers of California. This was especially true of the Donner Trail ski-areas and Yosemite. This was no doubt due to the fact that the Mount Rose area is on the east slope of the Sierras and, consequently, has colder snows.

After prolonged storms of wet or dry wild snows, the average skier should shun long slopes, especially if they are steep, open, or have little natural anchorage. Every year there are certain periods after storms of this type when the snow will avalanche at the slightest provocation. During these periods the skiers should confine their recreation to wooded or similar slopes where the snow has a great deal of natural anchorage. Resorts should prevent touring of their guests, if possible, during these times. This is especially true if the snow has fallen on a crust of any sort.

I believe a great deal of useful work can be done along the lines that I have suggested. There is certainly a great need for the education of the mass of new skiers in the fundamentals of snow-craft. After the skiers are familiar with primary conditions of snow, the problem arises as to how to give them information about the snow-conditions at particular areas. I feel that only by education of observers and the mass of skiers can this end be accomplished.

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## SKIING IN SOUTHERN CALIFORNIA: ESSENTIAL EQUIPMENT

R. C. Youngquist

In Southern California skiing is a new sport, which has developed tremendously in the last three or four years. In 1933, I had the pleasure of a mountaineering trip on skis to the top of San Gorgonio. This was a 22-mile round-trip from Barton flats at 6500 feet to the top which is at an elevation of 11,485 feet. At that particular time only seven persons made the trip. The public's opinion was that each of these persons was in some way mentally deranged. The season of 1939 finds literally thousands of persons buying any and all kinds of equipment, in anticipation of learning to ski and to experience the thrill of a down-mountain run.

There is a group in Southern California who do their mountaineering on skis. One of the requirements of this organization is to camp in the snow on at least one trip per year on the climb of some major mountain. The skiing that these men encounter is exactly comparable to that which the snow-surveyor encounters. The one difference, however, is that the snow-surveyor is concerned with the work of collecting data instead of the sport angle.

The equipment of these mountaineers is of prime importance. The skier's boots are of first significance. They should be of an excellent grade of leather and well made to stand the stresses to which they are put. Next in order of importance is the harness which holds the boot on the ski. The proper adjustment of the toe-irons of this harness should be such that the axis of the boot is in direct line with the axis of the ski. The skis, in my opinion, are of the third order of importance and for mountaineering or snow-surveying they should be equipped with steel edges in order to be able to traverse icy slopes encountered. The length of these skis should never exceed twice the length from the skier's hip bone to the floor in his stocking feet. This is the maximum length that the person can make a kick-turn with, which is a very important turn when skiing under heavy pack. For fresh and soft snows the width of the ski should be greater. The widest ski made at the present time is known by the trade name "Downhill." Ski-poles are a fourth order of importance, and should be of such a length that the distance from the snow-ring to the top of the pole is equal to the distance from the armpit to the floor. This length of pole has a great advantage over a shorter one on any long climb. There are many other items of equipment which are useful, but not of prime importance. A great deal of energy can be conserved by the use of the so-called climbing skins. The better grade of these is made of strips of seal skin with the hair pointing to the rear of the ski.

The last paragraph has departed from skiing as a sport, but may be of more importance to some members of snow-survey organizations. The one idea I would like to leave with those of you men who have charge of snow-survey crews is this: Do not send men who are unqualified in the rudiments at least of controlling skis under pack-load in a reasonable form of skiing technique, and, second, do not send them out with poor equipment. The best in equipment will conserve their energy and in so doing more data will be collected with the very minimum of personal error.

Department of Water and Power,
Los Angeles, California

## DISCUSSION

In the discussion of the waxing of skis, MR. YOUNGQUIST stated that of the many different kinds of trade-name waxes on the market, it all simmers down to the fact that beeswax is preferable for dry snow and resin-wax for wet snow. The proper waxing of skis is a conservation of energy. He also suggested the use of strip-skins for climbing. This increases the friction between the shoe and the snow-grain, thus conserving a great deal of energy on a long climb.

The need of ski-instinct and additional supplies of skis at shelter-cabins is brought home very forcibly in the following experience occurring in the Owens Basin after the meeting. The tale is reported by GEORGE A. LEWIS:

"Weather-forecasts for Monday, February 6, were dark and foreboding--everything from soup to nuts in the way of storms were forecast. It dawned clear and calm. So the day following, the boys took off, and had fine weather all week. Weather, however, is but one of the vicissitudes of the snow country. Vic Taylor and Ed Parker made the Cottonwood survey, and after completing their measurements at the 11,100-foot elevation they pointed the bed-slats for camp. Homeward bound--down hill, and good skiing. That's about all it takes to make any hydrographer happy. And then, in a few tense seconds, it was decidedly changed.

"Vic was breaking trail--swinging down a steep hillside in a wide telemark. Suddenly he whipped into a sharp Christie to avoid an exposed rock and his right ski broke in two. After Ed had dug him out of his retreat in the snowbank they sat down to think things over. What would you have done? Two men with heavy packs and only three skis. And miles from home. Well, they simply remembered the three-legged races they used to run at the County Fair, and applied the same logic to their situation. Ed and Vic came on into camp that night safe and sound, with one ski in the middle, to which each had fastened an opposite leg. Yes, they dug a lot of snow out of their ears on the way down--but by the time they reached camp they were making their turns like Sonja Heinie, and having a lot of fun at it. Once at camp, all was O.K., for at each snow-survey cabin an extra pair of skis is stored for just such an emergency."

The Rangers of the Tahoe National Forest under a plan inaugurated by DeWitt Nelson, Supervisor, attended a ski-school at the Big Bend Ranger Station near Cisco during the week starting January 16. Although such an extended course of instruction was an innovation in the Forest Service, it was believed that the increase in interest in snow-sports demanded that Forest Service officials be capable skiers.

A Winter-Sports Broadcast Service similar to that developed in recent years by the United States Bureau of Agricultural Engineering in the West is now being organized by the United States Weather Bureau in the Northeastern States. Because of the wide interest of the Western Interstate Snow-Survey Conference in Eastern problems as well as its own, a request was sent for a statement. The following letter of transmittal was received from Merrill Bernard, Chief of the River and Flood Division, United States Weather Bureau, Washington, D. C., dated December 14, 1938, together with later reports as the system got under way: "I am sending herewith a set of papers outlining a recently established winter-sports reporting service organized by the Weather Bureau for the Northeastern States. We shall be glad to have the benefit of any comment you may care to make on the organization."

## OUTLINE OF WEATHER BUREAU NORTHEAST STATES WINTER-SPORTS SERVICE

Merrill Bernard

The Weather Bureau, in response to the wide-spread demand on the part of winter-sports enthusiasts throughout the Northeastern States for reliable and unbiased information concerning skiing, tobogganing, skating, and other sports conditions, inaugurated a reporting service on December 2, 1938, to meet this public need.

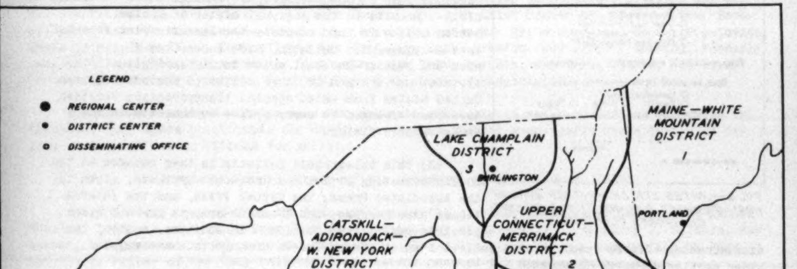
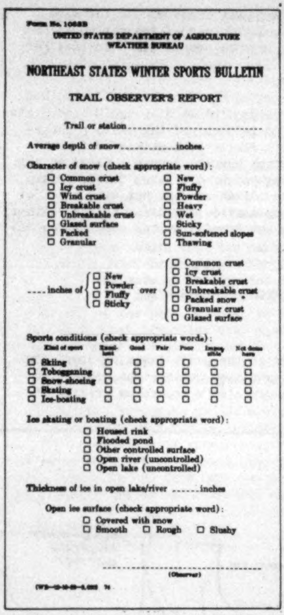

LEGEND
● REGIONAL CENTER
• DISTRICT CENTER
○ DISSEMINATING OFFICE
MAINE—WHITE MOUNTAIN DISTRICT
1
LAKE CHAMPLAIN DISTRICT
3
BURLINGTON
PORTLAND
UPPER CONNECTICUT—MERRIMACK DISTRICT
2
CONCORD
CATSKILL—ADIRONDACK—W. NEW YORK DISTRICT
4
ROCHESTER
SYRACUSE
BUFFALO
ALBANY
BOSTON
LOWER CONNECTICUT VALLEY DISTRICT
5
ITHACA
BINGHAMTON
PROVIDENCE
HARTFORD
NEW HAVEN
WESTERN PENNSYLVANIA—MARYLAND DISTRICT
6
SCRANTON
7
NEW YORK
EASTERN PENNSYLVANIA—NEW JERSEY DISTRICT
PITTSBURGH
READING
HARRISBURG
TRENTON
PHILADELPHIA
WASHINGTON

FIG. 1—NORTHEAST STATES WINTER SPORTS SERVICE



Form No. 1068B

UNITED STATES DEPARTMENT OF AGRICULTURE
WEATHER BUREAU

NORTHEAST STATES WINTER SPORTS BULLETIN

TRAIL OBSERVER'S REPORT

Trail or station ..............................

Average depth of snow ............ inches.

Character of snow (check appropriate word):

☐ Common crust
☐ Icy crust
☐ Wind crust
☐ Breakable crust
☐ Unbreakable crust
☐ Glazed surface
☐ Packed
☐ Granular
☐ New
☐ Fluffy
☐ Powder
☐ Heavy
☐ Wet
☐ Sticky
☐ Sun-softened slopes
☐ Thawing

.... inches of { ☐ New ☐ Powder ☐ Fluffy ☐ Sticky } over { ☐ Common crust ☐ Icy crust ☐ Breakable crust ☐ Unbreakable crust ☐ Packed snow ☐ Granular crust ☐ Glazed surface }

Sports conditions (check appropriate words):

| Kind of sport | Excellent | Good | Fair | Poor | Impossible | Not done here |
|---|---|---|---|---|---|---|
| ☐ Skiing | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| ☐ Tobogganing | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| ☐ Snow-shoeing | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| ☐ Skating | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| ☐ Ice-boating | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

Ice skating or boating (check appropriate word):

☐ Housed rink
☐ Flooded pond
☐ Other controlled surface
☐ Open river (uncontrolled)
☐ Open lake (uncontrolled)

Thickness of ice in open lake/river ...... inches

Open ice surface (check appropriate word):

☐ Covered with snow
☐ Smooth ☐ Rough ☐ Slushy

..............................
(Observer)

[illegible]

FIG. 2—UNITED STATES WEATHER BUREAU FORM (REDUCED ONE-HALF) FOR REPORT ON SPORTS CONDITIONS

The service, which will be expanded at an early date to include the winter-sports fields of Pennsylvania and New Jersey, is at present confined to five districts covering New England and New York State, as indicated in Figure 1.

The procedure of the reporting system is briefly as follows:

(1) In each district from 10 to 20 trail reporters in the field mail on Thursday morning to their respective district centers a complete report of sports conditions in their immediate vicinities. This report includes a description of snow and ice and the reporter's specific evaluation of the conditions with respect to each form of sport. A sample of the reporting card is shown by Figure 2. These cards are mailed to the respective district centers, that is, to Portland for the Maine-White Mountain District, to Concord for the Upper Connecticut-Merrimack District, to Burlington for the Lake Champlain District, etc.

(2) On Friday morning, with the trail reports before him (modified as necessary by telegraphic reports of any very marked changes in conditions since the Thursday mailing of the card), the district supervisor combines their contents into a coded telegraphic message which he immediately transmits to the regional office at Boston. The Boston office in turn combines the five district reports into a telegraphic bulletin, also coded, and including a week-end weather-forecast, which is redistributed to the district centers and 15 other cities in the northeastern United States from which special transportation services have been arranged to carry sports enthusiasts to the winter-sports fields.

(3) This telegraphic bulletin is then decoded at the 20 disseminating cities and broadcast by radio, given to the Associated Press, the United Press, and the International News Service, and local newspapers for the widest possible general publication. In addition, most of the disseminating offices issue printed bulletins which are mailed to transportation companies and other parties directly interested.

The following formal outlines and instructions have been issued December 12, 1938, by the River and Flood Division of the Weather Bureau of the United States Department of Agriculture.

### Northeast States Winter-Sports Service

In early December, the Weather Bureau began a snow-and-ice reporting service for the benefit of sportsmen and others interested in skiing, tobogganing, skating, and other winter sports in New England, New York, northeast Pennsylvania, and immediately adjacent areas. The region covered by the service is divided into the following districts. The Regional Office is located at Boston, Massachusetts.

| No. | District center | District |
|---|---|---|
| 1 | Portland, Maine | Maine-White Mountain |
| 2 | Concord, New Hampshire | Upper Connecticut-Merrimack |
| 3 | Burlington, Vermont | Lake Champlain |
| 4 | Albany, New York | Catskill-Adirondack |
| 5 | Hartford, Connecticut | Lower Connecticut |
| 6 | Pittsburgh, Pennsylvania | Western Pennsylvania |
| 7 | Scranton, Pennsylvania | Eastern Pennsylvania-New Jersey |

Outline of procedure:

(1) Postal-card reports (see Fig. 2) will be mailed by selected observers at each active trail on Thursday of each week, to reach district center Friday morning. These cards will number between 10 and 20 per district.

(2) From these cards, a coded telegraphic summary reporting conditions for each trail will be prepared at each district office and sent to Boston (Regional Office) on Friday morning.

(3) In addition, in order to provide up-to-date information in the event of marked changes since the Thursday card-report was mailed, four trail reporters in each district will be selected to telegraph direct to the district center and to Boston on Friday morning under certain specified conditions involving such changes.

(4) The Regional Office (Boston) will prepare a full regional bulletin for telegraphic and radio dissemination as shown below. This bulletin will contain a detailed statement of conditions throughout the region and will be concluded with a week-end regional weather-outlook, specifying probable conditions for each district for Saturday and Sunday.

(5) Dissemination of this bulletin will be as follows: In Boston--By radio from the Weather Bureau office, by bulletin to the Associated Press, United Press, International News Service, and local newspapers; and by telegraph (in code) to the following Weather Bureau offices, where it will be given to local newspapers and radio stations: Portland, Maine (Maine-White Mountain, District Center No. 1); Concord, New Hampshire (Upper Connecticut-Merrimack, District Center No. 2); Burlington, Vermont (Lake Champlain, District Center No. 3); Albany, New York (Catskill-Adirondack, District Center No. 4); Hartford, Connecticut (Lower Connecticut, District Center No. 5); Pittsburgh, Pennsylvania (Western Pennsylvania, District Center No. 6); Scranton, Pennsylvania (Eastern Pennsylvania-New Jersey, District Center No. 7); Washington, D. C.; Providence, Rhode Island; New Haven, Connecticut; New York, New York; Trenton, New Jersey; Reading, Pennsylvania; Philadelphia, Pennsylvania; Binghamton, New York; Buffalo, New York; Ithaca, New York; Rochester, New York; Syracuse, New York; and Harrisburg, Pennsylvania.

Arrangements will be made to make the bulletin available to railroad and bus companies interested, and, where practicable and desirable, a mimeographed snow-sports bulletin may be issued at Weather Bureau offices for mailing.

### Amendment No. 2: Winter-sports instructions (December 8, 1938)

The following, quoted from the Transactions of the American Geophysical Union, 19th Annual Meeting, 1938, is an extract from "The snow-terminology of ski-runners" by Henry I. Baldwin, New Hampshire Department of Forestry and Recreation. The definitions, from a compilation by Park Carpenter, Editor of the "Ski Bulletin," are hereby adopted for Weather Bureau use.

Soft-snow conditions:

Fluffy--Large, light, feathery flakes. Scooped up in the hand, it may be blown off like feathers. Even a tennis-ball would drop out of sight in an accumulation of sufficient depth.

Powder--Dry, cold, powdery snow; the perfect snow for sleighing and all winter sports.

New--(To be used for Weather Bureau purposes for snow which has fallen within 24 hours before trail report is made, and which cannot be described by some other term. That is, if the snow is new and fluffy, "Fluffy" will be checked; but if the snow is new and of a character for which no other term is listed here. "New" will be checked.)

Heavy--Occasionally a powder-snow, long before changing to crust, becomes somewhat packed or heavy, so that while skis sink in it readily, there is nevertheless a toughness to the surface which resists against lateral movement of the ski, causing slight difficulty in turning.

Sticky--Snow just beginning to melt. Sticky snow can be used by proper waxing of ski. "Powder-snow begins to stick if the air-temperature rises above the freezing point. Sticky snow adheres in big lumps to the running surface of the skis....Powder-snow begins to stick when it begins to thaw" [Arnold Lunn, Alpine skiing at all heights and seasons, p. 21].

Wet--A soggy state intermediate between sticky and slush reached after powder-snow or wind-crust has been thawing for some time. This is the cotton-batting snow from which boys roll big balls, build forts and snowmen.

Glazed--A light, thin, transparent glaze frequently forms on any one of the above-described sorts of soft snow. It is the result of superficial melting by hot Sun and subsequent freezing. It does not materially hinder use of ski.

Slush--(For Weather Bureau purposes check "Thawing.")

Hard-snow conditions (crusts):

Breakable--A crust is "breakable" when it will not hold the full weight of a man on a single ski. This condition renders steering difficult except by jump-turn, and when present should always be reported even though the report also shows several inches of soft snow above the crust. All crusts are first classified as "breakable" or "non-breakable." For practical purposes a person not using ski may test a crust by selecting a board three inches wide and having roughly one inch of length for each two pounds of the person's weight. If the crust breaks when he stands on this board, it is to be reported with the word "breakable."

Wind--"Wind"-crust is frequently formed by action of the wind on powder-snow. Usually ripple-marks on the surface reveal the origin of this crust. If breakable, report "breakable wind"; otherwise merely "wind." (For Weather Bureau purposes, do not use the combined term "breakable wind"; "breakable" is sufficient.)

Common--"Common" crust is the crust formed by light thaw and refreezing; it should, if not "breakable," be reported simply as "common."

Icy--"Icy" crust is the hard, ice-like crust formed by freezing of a watery surface after a heavy thaw. Skis, even when sharply edged, get no grip on this surface, which makes skiing quite impossible. Such crust should be reported merely with the one word "icy."

Spring conditions:

Granular--An old, wet snow, in appearance and consistency much like the wet rock-salt used to pack ice-creams. Granular snow is usually found only in the spring and at high altitudes. "Snow that has been melted and refrozen night after night soon acquires a crystalline character.....Granular snow yields excellent skiing" [Lunn].

## Winter-sports code, December 22, 1938
(Including all amendments to No. 3)

The code for use between snow-district and regional offices, and between regional and disseminating offices in accordance with outline approved by the Acting Chief of Bureau, dated November 18, 1938, is as follows:

The first word in the report will be the station or trail name, following which code-groups of not exceeding five letters each will be arranged in the following order:

First letter group--This group will contain three letters when only one kind of snow is present, and five letters when the surface-snow is of a different kind than the underlying layer. The first two letters will give the average depth of snow at the station, as shown in Table 1. The third, fourth, and fifth letters will describe the snow at the station, using Tables 1-a and 2, thus, for example:

| | |
|---|---|
| Average depth at station 14 inches, common crust . . . . . . . . . . . . | BEC |
| Average depth at station 21 inches, 6-inch powder over unbreakable crust . . | DUIWM |
| Average depth not reported, 3-inch sticky snow over breakable crust. . . . . | XXATL |

Second letter group--As indicated in Table 3, this group will always contain five letters. The order of sport conditions will be as follows: Skiing; tobogganing; snow-shoeing; skating; ice-boating. For example:

| | |
|---|---|
| Skiing good, tobogganing excellent, snow-shoeing not reported, skating poor, ice-boating impossible. . . . . . . . . . . . . . . . . . . . . . . . . | EAXOU |
| Skiing poor, tobogganing fair, snow-shoeing fair; skating not done, ice-boating not done. . . . . . . . . . . . . . . . . . . . . . . . . | OIIJJ |
| Skiing fair, tobogganing not reported, snow-shoeing not reported, skating good, ice-boating not reported. . . . . . . . . . . . . . . . . . | IXXEX |

Third letter group--This group will be used to indicate the thickness and describe the surface of natural (open lake or river) skating or ice-boating surfaces only. When the skating rink is controlled (as in the case of ponds, housed rinks, and flooded lots) this letter group will be omitted. When used, the first two letters will give the thickness of ice using Table 1, and the third letter will describe the ice using Table 4, for example:

| | |
|---|---|
| Ice, 8 inches thick, covered with snow | ZOV |
| Ice, 13 inches thick, clear of snow, surface rough | BAR |
| Ice, 7 inches thick, clear of snow, surface slushy | ISH |

Examples of reports:

| | |
|---|---|
| Red Lake average snow-depth 5 inches, 2 inches sticky snow over icy crust, skiing poor, tobogganing fair, snow-shoeing not reported, skating excellent, ice-boating good, ice on lake 8 inches thick smooth | Redlake ESATK OIXAE ZOS |
| Davis Hill average snow-depth 19 inches, 3 inches powder over unbreakable crust, skiing excellent, tobogganing good, snow-shoeing fair, skating in flooded pond excellent, no ice-boating | Davishill BOAWM AEIAJ |
| Deer Park average snow-depth 14 inches, common crust, skiing good, tobogganing excellent, snow-shoeing excellent, no skating, ice-boating not reported | Deerpark BEC EAAJX |
| Bear River snow in patches sticky, skiing tobogganing snow-shoeing impossible, skating poor, ice-boating excellent, ice in open river 7 inches rough | Bearriver ZUT UUUOA ISR |
| Bald Knob (total depth not reported) 5 inches fluffy over glazed surface, skiing poor, tobogganing good, snow-shoeing skating ice-boating not reported | BaldKnob XXEFG OEXXX |

## Winter-sports code-letters

### Table 1--Average total depth of snow or thickness of ice, in inches

(First two letters in first and third groups)

| | | | | | |
|---|---|---|---|---|---|
| None | UU | 10 | BU | 32 | FA |
| Patches or very thin | ZU | 12 | BA | 34 | FE |
| 1 | US | 14 | BE | 36 | FI |
| 2 | ZA | 16 | BI | 38 | FO |
| 3 | AS | 18 | BO | 40 | GU |
| 4 | ZE | 20 | DU | 42 | GA |
| 5 | ES | 22 | DA | 44 | GE |
| 6 | ZI | 24 | DE | 46 | GI |
| 7 | IS | 26 | DI | 48 or over | GO |
| 8 | ZO | 28 | DO | Unknown, unreported, omitted | XX |
| 9 | OS | 30 | FU | | |

### Table 1-a--Average depth of surface-snow covering base-layer

| | | | | | |
|---|---|---|---|---|---|
| Less than one-half inch | Z | 4 inches | E | 10 inches or more | U |
| 1 inch | S | 6 inches | I | Unreported or unknown | X |
| 2 inches | A | 8 inches | O | | |

### Table 2--Snow

| | | | | | |
|---|---|---|---|---|---|
| Common crust | C | Packed | P | Wet | S |
| Icy crust | K | Granular | R | Sticky | T |
| Wind crust | D | New | Q | Sun-softened slopes | N |
| Breakable crust | L | Fluffy | F | Thawing | H |
| Unbreakable crust | M | Powder | W | Unreported or unknown | X |
| Glazed surface | G | Heavy | V | | |

Table 3--Sports (skiing, tobogganing, snow-shoeing, skating, ice-boating)
(Second group)

| | | | | | |
|---|---|---|---|---|---|
| Excellent | A | Fair | I | Impossible | U |
| Good | E | Poor | O | No activity | J |

Unreported or unknown X

Table 4--Natural ice-conditions
(Third letter in third group)

| | |
|---|---|
| Covered with snow | V |
| Rough | R |
| Smooth | S |
| Slushy | H |

Table 5, summarized from Winter-Sports Bulletins for February 10, 1939, shows the lack of uniformity in snow-conditions that may exist in the same district even when the weather-conditions are uniform over the entire Northeast.

Table 5--Summary of Winter-Sports Bulletins of United States Weather Bureau for February 10, 1939

| District and area | Locality or trail | Snow | | Sports<br>Exc = excellent; G = good; F = fair; P = poor; Imp = impossible; XA = no activity; XR = no report | | | | | | Ice | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Average depth, inches | Description (Example: 2" powder over breakable crust) | Skiing | Tobogganing | Snow-shoeing | Skating | Ice-boating | Sledding | Thickness, inches | Condition of surface |
| No. 1, Portland, Maine, Maine-White Mountain Area | Alfred | 8 | 1" common crust over packed | P | P | P | IMP | XA | | 16 | Snow-covered |
| | Cumberland | 8 | Powder surface | EXC | EXC | EXC | XR | XR | | 10 | Covered |
| | Damariscotta | 8 | Powder | EXC | EXC | F | F | XR | | 14 | Covered |
| | Camden | 14 | 2" powder over packed | EXC | EXC | EXC | G | XR | | 20 | Smooth |
| | Shawmut | 14 | 1" powder over packed | EXC | G | G | IMP | IMP | | 18 | Covered |
| | Douglass Hill | 20 | 1" powder over packed | EXC | EXC | EXC | XA | XA | | | |
| | Wilsons's Mills | 32 | 10" powder over breakable crust | F | G | P | IMP | XA | | 22 | Covered |
| | South Paris | 14 | 4" powder over packed | EXC | XA | EXC | P | P | | 16 | Covered |
| | Richmond | 12 | Powder | EXC | EXC | EXC | P | IMP | | 12 | Covered |
| | Durham | 9 | 2" powder over breakable crust | EXC | EXC | G | IMP | XA | | 18 | Covered |
| Forecast: Snow, warmer tonight; Saturday snow, colder Saturday night; Sunday, fair and continued cold. | | | | | | | | | | | |
| No. 2, Concord, New Hampshire, Upper Connecticut—Merrimack Area | Newport | 10 | 4" new over common crust | EXC | XA | G | P | XA | | | |
| | St. Johnsbury | 14 | 10" new over unbreakable crust | EXC | EXC | EXC | EXC | XA | | | |
| | Hardwick | 22 | 2" new over wind crust | G | G | G | XA | XA | | | |
| | Bradford | 16 | 10" powder over granular | EXC | G | EXC | G | XA | | | |
| | Lancaster | 20 | 10" powder over common crust | EXC | EXC | EXC | EXC | XA | | | |
| | Woodsville | 14 | 4" fluffy over powder | EXC | XA | EXC | EXC | XA | | | |
| | Warren | 42 | 10" powder over packed | EXC | F | EXC | XA | XA | | | |
| | Waterville Valley | 48 | Powder surface | EXC | EXC | EXC | XA | XA | | | |
| | North Woodstock | 28 | 10" powder over unbreakable crust | EXC | EXC | EXC | EXC | XA | | | |
| | Pinkham Notch | 38 | Powder surface | EXC | XA | EXC | XA | XA | | | |
| | Tuckerman's Ravine | 48 | Powder surface | EXC | XA | EXC | XA | XA | | | |
| | Hanover | 14 | 10" powder over packed | EXC | G | G | XR | XR | | | |

Table 5--Summary of Winter-Sports Bulletins of United States Weather Bureau for February 10, 1939--Continued

| District and area | Locality or trail | Snow | | Sports<br>Exc = excellent; G = good; F = fair; P = poor; Imp = impossible; XA = no activity; XR = no report | | | | | | Ice | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Average depth, inches | Description (Example: 2" powder over breakable crust) | Skiing | Toboganing | Snowshoeing | Skating | Ice-boating | Sledding | Thickness, inches | Condition of surface |
| No. 2--Continued | Plymouth | 20 | 4" powder over packed | G | G | G | XR | XA | | | |
| | Newfound Region | 30 | 6" new over packed | EXC | EXC | EXC | F | IMP | | 18 | Covered |
| | Alexandria | 22 | 2" powder over packed | EXC | XA | G | XA | XA | | | |
| | Andover | 14 | 10" new over granular | EXC | EXC | EXC | EXC | XA | | | |
| | Laconia-Guilford | 18 | 4" powder over packed | EXC | EXC | EXC | EXC | P | | 14 | Covered |
| | Pittsfield | 12 | 4" powder over packed | EXC | EXC | EXC | XA | XA | | | |
| | Concord | 10 | 1" new over granular | G | G | G | IMP | XA | | 16 | Covered |
| | Deerfield | 7 | 4" powder over packed | G | XA | XA | XA | XA | | | |
| | Brookline | 12 | 4" new over powder | EXC | EXC | EXC | EXC | XA | | | |
| | Cannon Tramway | 48 | 10" powder over packed | G | XA | XA | XA | XA | | | |
| Forecast: Snow, warmer tonight; Saturday snow, colder Saturday night; Sunday fair and continued cold. | | | | | | | | | | | |
| No. 3, Burlington, Vermont, Lake Champlain Area | Burlington | 5 | Common crust | G | G | F | P | XA | | | Covered |
| | Under Hill | 24 | Wind crust | EXC | G | G | XA | XA | | | |
| | Montpelier | 16 | 8" fluffy over powder | EXC | EXC | G | EXC | XA | | | |
| | Northfield | 16 | 10" powder over common crust | EXC | G | G | XA | XA | | | |
| | Waterbury | 10 | 4" powder over packed | EXC | G | G | XA | XA | | | |
| Unofficial reports indicate excellent snow-conditions generally throughout district; skating and ice-boating generally poor.<br>Forecast: Rain or snow tonight; Saturday light snow and colder; Sunday fair, continued cold. | | | | | | | | | | | |
| No. 4, Albany, New York, Catskill-Adirondack Area | Allegany and Bear Mountain | 3 | Glazed surface over powder | | | | | | | | |
| | Copake Falls | 8 | Common crust | EXC | XA | G | IMP | XA | | | 10" snow-covered |
| | Lake George | 20 | 4" new snow | EXC | XR | XR | XR | XR | | | |
| | Lake Placid | 12 | 4" powder over packed | EXC | | | | | | | |
| | Liberty | 10 | 4" glazed surface over powder | EXC | | | | | | | |
| | North Creek - Top | 30 | 10" glazed surface over unbreakable crust | EXC | XA | EXC | XR | XR | | | |
| | North Creek - Slopes | 10 | 6" new over unbreakable crust | EXC | EXC | EXC | EXC | XA | | | |
| | Old Forge | 20 | 4" powder surface | EXC | | | | | | | |
| | Phoenicia | 20 | 4" powder crust surface | EXC | | | | | | | |
| | Speculator | 36 | 8" powder surface | G | | | | | | | |
| | Ticonderoga | 18 | Powder surface | EXC | | | | | | | |
| | Thunderbolt | 38 | 2" powder surface | G | | | | | | | |
| | Pittsfield | 12 | 4" powder surface | G | | | | | | | |
| | Beartown | 14 | Powder | G | | | | | | | |
| Forecast: Rain or snow tonight; Saturday light snow and colder; Sunday fair, continued cold. | | | | | | | | | | | |

Table 5--Summary of Winter-Sports Bulletins of United States Weather Bureau for February 10, 1939--Concluded

| District and area | Locality or trail | Snow | | Sports (Exc = excellent; G = good; F = fair; P = poor; Imp = impossible; XA = no activity; XR = no report) | | | | | | Ice | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Average depth, inches | Description (Example: 2" powder over breakable crust) | Skiing | Tobogganing | Snowshoeing | Skating | Ice-boating | Sledding | Thickness, inches | Condition of surface |
| No. 5, Hartford, Connecticut, Lower Connecticut Area | Hartford | 4 | Sticky | IMP | IMP | IMP | IMP | IMP | | | |
| | Norfolk, Coolwater | 16 | 6" powder over unbreakable crust | EXC | EXC | G | IMP | XA | | 10 | Covered |
| | Simsbury | 4 | Common crust | P | P | IMP | IMP | XA | | 8 | Covered |
| | East Hartland | 8 | Common crust | F | F | G | XR | XR | | 12 | Covered |
| | Huntington | 10 | Heavy | G | F | XR | XR | XR | | | |
| | Holyoke | 8 | Surface unreported | F | F | XR | XR | XR | | 8 | Covered |
| | Monadnock | 16 | 10" fluffy over powder | G | G | G | G | XA | | 14 | Smooth |
| Forecast: Rain tonight; Saturday partly cloudy and colder; Sunday fair and continued cold. | | | | | | | | | | | |
| No. 6, Pittsburgh, Pa., Western Pa. Area | Kane | 10 | Common crust | G | EXC | F | EXC | XA | | | |
| | Deer Valley | | | IMP | IMP | IMP | IMP | IMP | | | |
| No. 7, Scranton, Pa., Eastern Pa.-New Jersey Area | Mt. Pocono | 5 | Packed | G | G | XA | G | G | | 14 | Smooth |
| | Skytop | 7 | Unbreakable crust | G | EXC | F | | XA | | 14 | Smooth |
| | Cresco | | Common crust | P | F | IMP | P | XA | | 8 | Unreported |

River and Flood Division,
U. S. Weather Bureau,
Washington, D. C.

## DISCUSSION

The following letters of December 8, 1938, and February 13, 1939, from Regional Director FRANK R. KITTREDGE of the National Park Service, Region Four, San Francisco, California, to Dr. Church voice the national interest of the Park Service in snow-problems as expressed earlier by Director Arno B. Cammerer himself.

"Your letter of December 5, 1938, in regard to the Snow-Survey Conference has been received with a great deal of pleasure as from the program it is very apparent that some interesting meetings are going to result. I have directed our Regional Engineer, R. D. Waterhouse, to attend the Los Angeles meeting, and he will be present throughout the Conference. If possible, our Inspector in Idaho, Grant Ross, or our Supervising Engineer, C. E. Drysdale, will attend the Spokane Conference.

"The above-mentioned gentlemen are all familiar with snow-conditions in the Parks, together with snow-sports, particularly Mr. Waterhouse who, for the past ten years, has observed and reported on snow-removal work in our areas, more especially in Mount Rainier National Park, which has been our first-rank snow-sports area, and where snow-removal from roads and snow-study have been carried on probably longer than in any other of our areas."

"There is enclosed herewith resumé of the remarks made by Mr. Waterhouse at your December 16, 1938, meeting of the Western Interstate Snow-Survey Conference. While Mr. Waterhouse was present merely as an observer, he reports that a vast amount of territory has been covered by your Committee and that from all indications very much good can result. We all hope that your group continues as it has been doing."

## SNOW-ACTIVITIES OF THE NATIONAL PARK SERVICE

R. D. Waterhouse

The National Park Service has been measuring and reporting on snow in the areas administered by it for many years, both for its own information and for the Weather Bureau.

For the past five years radio has played an important part in snow-reporting as daily reports are sent in to the Weather Bureau and a short while later the weather-forecast is received via radio. In the State of Washington this is done through the Seattle Office of the State Highway Department as part of the reporting system of the State, and by $8^h\ 30^m$ in the morning weather- and road-conditions for the entire State are compiled and broadcast to all State Highway Maintenance offices, as well as to Mount Rainier National Park. In this way shippers are advised of road-conditions and are also advised as to prevailing temperatures and other conditions which must be known to properly protect shipments by truck on the highways.

Daily reports are also made by radio on snow-conditions with regard to skiing in Mount Rainier National Park; the pleasure of the skiing fraternity is protected thereby, since they have up-to-the-minute and accurate skiing information before they start for the skiing slopes.

From the viewpoint of the National Park Service, the "Snow-surveyor's manual" by James C. Marr is of very great interest. It reflects the vast amount of time which Mr. Marr has put into the subject and covers very important items in connection with irrigation, water-supply, flood-control, and related subjects which are entirely influenced by snowfall and conditions in the higher elevations. The National Parks, on account of their geographical location at the summit of watersheds and at the headwaters of the streams, are in the strategic position for observing and reporting snow-conditions, as touched upon in this manual.

In forecasting flood-conditions and irrigation-water storage from snowfall and snowpack in the mountains, it is necessary to frequently measure snow-depth, water-content, etc., which the Park Service has been doing for some years. The Park Service, however, has not interpreted the results obtained and Mr. Marr's manual giving the proper coordination of measurements fits into the National Park Service picture very nicely. In this connection it is the opinion of the writer that the index of wetness, that is, the amount of water stored in the ground in the fall, must have a very great bearing on forecasting of conditions which will obtain the following spring.

In snow-removal work from highways, the National Park Service has been a pioneer, having used snow-removal equipment of the rotary type continuously and consistently since rotary equipment first came upon the market. The Service has contributed to the development of this kind of equipment by assisting in designing an auxiliary piece of snow-removal equipment, known as the Hewitt snow-plow, which was worked out by the mechanical personnel of Mount Rainier National Park. The Service has also pioneered in clearing of roads into the ski country and is vitally interested in the problems of the visitors who enjoy skiing.

Because of their geographical location, the National Parks probably have the best skiing terrain in the United States.

The work of the Western Interstate Snow-Survey Conference is of great practical use and is very interesting to the National Park Service. Snow-conditions prevail in many of our park-areas from five to seven months of the year, and you may rest assured that the Service will cooperate with your Conference in every way possible to make your work a success.

National Park Service,
San Francisco, California

MR. WATERHOUSE stressed the need of including the item of index of wetness in Mr. Marr's "Snow-surveyor's manual," and stated that any of the observations by the National Park Service are at the disposal of the members of the Western Interstate Snow-Survey Conference. He discussed the ski fad and stated the cost of keeping the roads open for snow-sports. The costs range as high as $0.75 per person. It is his belief that the activities of the National Park Service, when coordinated, will greatly help snow-surveys.

# PROGRESS AND POLICY

## PROGRESS-REPORT OF WESTERN INTERSTATE SNOW-SURVEY CONFERENCE

H. P. Boardman, Chairman, Executive Committee

The first and most important task confronting the organization after the Davis meeting of January 7 and 8, 1938, was preparing for printing the papers and discussions presented at that meeting. In this connection Dr. Church, with his efficient assistants, did the lion's share of the work.

Assembling the papers and discussions, editing them, having them checked by their authors, and sending them to the Washington office of the American Geophysical Union entailed considerable work. The next task was to raise the funds for covering expenses of publication. Dr. Church rightly decided correspondence to raise such funds was no job for an engineer and the engineer at this end of the line willingly agreed with him. However, another engineer in the south, James Jones of Los Angeles, did his share of this work to redeem in a measure the reputation of his profession. How good Dr. Church's judgment was and how skillfully he worded his letters are attested by the fact that a total of $735 was subscribed. This will leave on hand nearly $90 barring unforeseen incidentals. The main items of expense were for publishing the proceedings in the "Transactions" of the American Geophysical Union, the printing of 2400 reprints, freight from Washington to Reno, and postage for mailing. Originally 2000 reprints were ordered, but the numerous requests for copies to be mailed made it necessary to increase the order to 2400. A large number of copies have been mailed direct from the Washington office of the General Secretary of the American Geophysical Union.

The contributors include United States and Canadian public organizations (federal, state, county, and municipal), agricultural experiment stations, and hydroelectric power-companies. A list of these contributing agencies is published in the report of the Davis meeting.

Some of these organizations had to make their contributions by subscribing for a number of the reprints which they planned to supply to their employees or other interested parties. Exchange of mailing lists with Dr. Church's office aims to avoid waste through duplication in mailing more than one copy to any individual.

The Washington office of the American Geophysical Union has cooperated splendidly and would have stood a portion of the expense had it been necessary, but fortunately the response to solicitations has been generous and this is a good indication of the growing interest in snow-surveying and belief in its practical usefulness as well as scientific value.

Consideration of the future status of the Western Interstate Snow-Survey Conference will be in order at the Los Angeles and Spokane meetings if thought desirable, but, in view of the harmonious relations with the Section of Hydrology of the American Geophysical Union and the difficulty of finding any other organization with which we could obtain such good reciprocal cooperation, I think we should continue the present arrangement indefinitely.

The consideration of a change in the personnel and especially the advisability of increasing the number on the Executive Committee is in order at these two meetings.

University of Nevada,
Reno, Nevada

## FINANCIAL REPORT OF PUBLICATION OF PROCEEDINGS OF DAVIS MEETING

J. E. Church

The present report differs from that made at Los Angeles only in its totals, for all pledges have now been fulfilled and all debts paid.

The publication of the proceedings has been made possible through donations for printing and orders for reprints. The number of organizations engaged in the effort was 21. To them detailed acknowledgment has been made in the Davis proceedings. The American Geophysical Union bore the overhead of publication.

In most cases the reprints were ordered through the Executive Committee of the Conference but in some cases directly from the American Geophysical Union. The following tabulation therefore represents the entire transaction and balance in the publication fund. The balance will be applied toward cost of publishing the proceedings of the Los Angeles and Spokane meetings.

| | | |
|---|---|---|
| Receipts: | | |
| Contributions and sales of reprints | | $735.00 |
| Disbursements: | | |
| Printing proceedings as part of "Transactions" of American Geophysical Union | $228.00 | |
| 2400 reprints | 341.82 | |
| Freight on reprints | 22.62 | |
| Stamps for distribution of reprints | 52.87 | 645.31 |
| Balance on hand | | $ 89.69 |

Other routine expenses incurred in editorial and clerical work including routine material connected with the work of the Executive Committee of the Snow-Survey Conference have been generously borne by the Nevada Agricultural Experiment Station, founder and patron of snow-surveying.

University of Nevada,
Reno, Nevada

## DISCUSSION AND RESOLUTIONS ADOPTED

JAMES E. JONES, Chairman of the Dinner Meeting, stated that the financial statement shows the organization to be on the credit side of the ledger and all bills paid. He asked an expression of opinion as to the continuing of the present Committee until some other time when we should have a full meeting.

DR. J. E. CHURCH suggested that the Soil Conservation Service and the National Park Service also be given representation on the Committee. He suggested also that the contacts of the organization be kept up with the American Geophysical Union, that the present method of obtaining funds be continued, as in the past, by contributions from the large corporations and governmental agencies profiting from the knowledge and experience of their employees through the Snow-Survey Conference, and that representatives be obtained from a larger section of the country.

FRED H. PAGET stated that he was in favor of a smaller Committee due to the fact that with a large Committee more work is placed on the Chairman, and also that it would be quite difficult for the Chairman to decide on account of dissenting opinions.

A long discussion followed relative to the merits and demerits of enlarging the Committee.

MR. JONES stated that he believed the present organization was fully representative of the Western States, and suggested that the Conference continue to function with the present Committee, without expansion, until such time as a meeting could be held as a whole instead of in sections as at the present time.

Resolution I--W. A. LANG moved "That until a meeting is held more completely representing the entire Western Interstate Snow-Survey Conference, at which more concerted action can be taken, it is the desire of the members here assembled that the present Executive Committee continue in office, and that no additional members be added to the Committee."

GEORGE A. LEWIS suggested that the Committee determine future meeting date, and James E. Jones was instructed to contact Chairman Boardman and the rest of the present Committee, expressing to them the desire of the group that the present Committee continue to function until relieved by a plan agreeable to the Conference as a whole.

A plan of selection of committeemen by mail ballot, with a given number in definite districts was suggested, but no decision was reached.

J. E. PHILLIPS believed that, while probably a more definite organization would be advisable, the organization should continue on its own as in the past.

JAMES C. MARR suggested that the American Geophysical Union would accept this organization and that probably the Snow-Survey Conference might be affiliated with the Union.

GEORGE A. LEWIS believed that the organization should cooperate with all, but affiliate with none.

Resolution II--A. R. CODD moved "That the matter of affiliation with any other organization be dropped and that the Western Interstate Snow-Survey Conference continue to function by maintaining its present informal connection with the American Geophysical Union."

JAMES E. JONES suggested that the method of obtaining finances be as they have been in the past.

Resolution III--MR. ELGES moved "That inasmuch as the publication of documents has in the past been successfully accomplished by means of contributions from interested organizations, it is the opinion of the members here assembled that this method should be adhered to in the future."

Following adjournment at 11:00 p.m. F. B. LAVERTY pointed out that the inherent difficulty of the present organization was the desire for local self-government and the oversize of the area now administered. He suggested, therefore, that local executive committees be substituted for the larger Western Committee.

Such a plan could readily be carried out by providing for four Regional Committees similar to those of the Section of Hydrology of the American Geophysical Union; for example, North Continental Divide, South Continental Divide, North Pacific Coast, and South Pacific Coast. However, a joint chairman or other central direction should be provided as is done in the American Geophysical Union and questions of mutual interest referred to the meetings of the Conference in the various regions. Elections can readily be help by ballot as is done in the Sierra Club and others of national expanse.

In fulfillment of the purpose voiced at the meeting, a formal letter was written by Mr. Jones to Chairman Boardman as follows:

"It is hoped that action by the Spokane meeting will be along similar lines and that a method of operation be worked out during the coming year, looking towards a more regular choice of Committee upon lines paralleling, probably, the Engineering Society. I have extended my personal thanks to Prof. M. R. Huberty and the Section of Hydrology for the personal assistance and other cooperation given us in the matter of the meeting arrangements, but would ask that you, as Chairman, extend the official thanks to the Committee."

# AMERICAN GEOPHYSICAL UNION
# TRANSACTIONS OF 1939

## PART I

## REPORTS AND PAPERS
## JOINT REGIONAL MEETING
## SECTION OF HYDROLOGY
## AND
## WESTERN INTERSTATE SNOW-SURVEY CONFERENCE

## (B) NORTH CONTINENTAL DIVIDE AREA

SPOKANE, WASHINGTON, DECEMBER 28, 1938

PUBLISHED BY THE NATIONAL RESEARCH COUNCIL
OF
THE NATIONAL ACADEMY OF SCIENCES
WASHINGTON, D. C.
JULY, 1939

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## INTRODUCTION

O. W. Monson, Presiding

The Conference began with a breakfast meeting at the Davenport Hotel, December 29, 1938. The following members were present: H. P. Boardman, James E. Church, Ashton R. Codd, D. B. Freeman, H. T. Gisborne, L. T. Jessup, James C. Marr, O. W. Monson, and R. A. Work.

This meeting enabled the members to get acquainted with the purposes of the two organizations. Dr. Church, Vice-President of the Section of Hydrology of the American Geophysical Union, described its purposes and scope of activity, and explained the reasons for the regional committees [see "Transactions, Denver Meeting, 1937," pp. 510-514]. He also announced the Seventh Triennial Assembly of the International Union of Geodesy and Geophysics to be held at Washington during September 4-15, 1939, under the auspices of the American Geophysical Union with the cooperation of the National Research Council.

Dr. Church also described the organization of the Western Interstate Snow-Survey Conference and introduced Professor Boardman, Chairman of the Executive Committee [see "Transactions, Davis Meeting, 1938," pp. 736-743].

After this informal meeting, adjournment was taken until after the general session of the Northwest Scientific Association, when the Section and Conference met jointly as the Hydrology-Snow-Survey Section of the Association.

## SECTION OF HYDROLOGY

O. W. Monson, Presiding

Chairman MONSON read the following letter dated December 13, 1938, from L. K. Sherman, President of the Section of Hydrology of the American Geophysical Union:

"Yours of December 2, 1938, is at hand. I am pleased to see that you are going ahead with the meeting at Spokane on December 28 and 29.

"Your Committee has arranged an excellent program. In some respects, it is unique. You cover two or three specific topics very thoroughly by assignment of four eminently qualified individuals to each subject. I am of the opinion that this procedure may be carried out to advantage in some of our other meetings.

"Much to my regret, I have had to cancel my Western trip entirely. My work is of such an intermittent nature in a business way that I have to attend to it if and when it comes.

"I wish to extend my appreciation to you and the members of your Committee for their work. May you have a most successful meeting."

Dr. CHURCH gave a brief explanation of the purposes of the Section and of the beginning and development of the science of snow-surveys. A great deal of interest has developed in this new science, but many problems still remain to be solved. For the future he advised continuation of interest in this work with free interchange of ideas between members of the Committee rather than encouraging a regular meeting each year for which formal papers should be prepared.

## SYMPOSIUM ON THE LIMIT OF PRACTICABLE USEFULNESS OF SNOW-SURVEYS MADE IN THE HEADWATER-REGIONS WHEN USED FOR PREDICTING RUN-OFF AT LOCALITIES QUITE REMOVED FROM THE COURSES

### FORT PECK RESERVOIR

D. B. Freeman

A foreknowledge of the probable runoff from large drainage-areas at points quite distant from the headwater-regions is of great value in connection with the problems involved in the disposition and control of this water. During dry periods it is helpful in the allocation and conservation of water; during wet periods it is helpful in the conservation of life and property from high water.

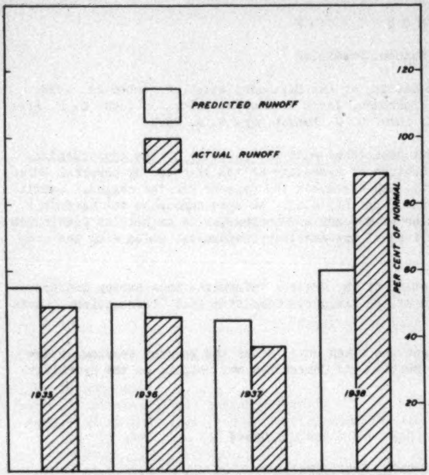

FIG. 1—ACTUAL AND PREDICTED RUNOFF ABOVE FORT PECK, APRIL TO JULY, INCLUSIVE

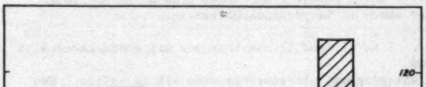

FIG. 2—ACTUAL PRECIPITATION AND RUNOFF ABOVE FORT PECK, APRIL TO JULY, INCLUSIVE

A prediction of the "spring" runoff at Fort Peck, which is made each year in the Division Office of the Corps of Engineer at Kansas City, is one example of the prediction, from snow-surveys, of runoff at a locality quite removed from the snow-courses. Fort Peck is situated about 225 miles below the nearest snow-course, and the climatic and topographic characteristics of the terrain below the headwater-regions where the courses are located are materially different from those in the headwater-regions.

Since 1934, snow-surveys have been carried on jointly by the Corps of Engineers and the United States Geological Survey for use in these prediction-studies. Considerable information has been accumulated by the two agencies in their respective offices at Kansas City and Helena. Records of precipitation, temperature, snowfall, and runoff have been compiled and analyzed and are all used in the prediction-studies.

As a result of the studies made to date, it would appear that predictions of runoff for years in which precipitation in the form of rainfall is comparatively small can be made quite accurately. In the Upper Missouri River Basin the rainfall during the years 1934 to 1937, inclusive, was consistently below "normal." The predicted "spring" runoff for these years was remarkably close to the actual runoff. The greatest divergence was in 1937, when the actual runoff was approximately 37 per cent of "normal," and the predicted runoff was 45 per cent of "normal."

By way of contrast with the conditions which obtained during 1934 to 1937, conditions in the spring of 1938 were such that a much larger portion of the runoff was a direct result of rainfall, which was above "normal," and which occurred both during and after the snow-surveys. Although the actual snow-depths and densities in 1938 were not materially different from those that obtained in 1937, the actual runoff at Fort Peck in 1938 was much greater than it was in 1937 and for a number of years prior to that time.

The inaccuracy of the prediction in 1938, which was based on the same methods as had been used previously, was much greater than it had been during any of the dry years. The explanation lies mainly in the fact that a relatively large amount of the runoff this year was a direct result of rainfall, and consequently was not a direct function of the water-content or depth of the snow-blanket. For this reason, the limits of practicable usefulness of snow-surveys for localities quite removed from the courses depend largely upon the extent to which correct evaluation can be made of the proportion of runoff which should be attributed to snow-melt and the proportion of runoff which should be attributed to rainfall and other interrelated factors.

The effect of rainfall has been considered in arriving at the predictions of runoff for Fort Peck. However, the experience in 1938 would seem to emphasize the need for a much fuller knowledge of the effect of rainfall and other factors on runoff when the distance intervening between the snow-courses and the locality for which the prediction is made is great.

It would appear that there is a field for much study in this connection, and that the limit of practicable usefulness of snow-surveys made in the headwater-regions, when used for predicting runoff at localities quite removed from the courses, will depend largely upon the knowledge gained from this study. The acquirement of this knowledge is important in order that full advantage may be taken of these predictions and, during critical periods, in order that serious mistakes may be avoided.

Engineer, In Charge of Reservoir Regulation Section,
Missouri River Division Office,
Corps of Engineers, United States Army,
Kansas City, Missouri

## NORTHERN ROCKY MOUNTAINS

H. T. Gisborne

I have no data, no experience, and no opinion of the maximum or average distance from a snow-course or series of courses at which the snow-measurements are applicable in predicting runoff. I see one need, however, for determining such distances. This need definitely affects the "practicable usefulness" of snow-surveys, and is a need which might be overlooked in discussing this question.

The headwaters of many if not most streams in the northern Rocky Mountains are within the National Forests, and the obligation and expense of protecting these headwaters from devastation by fire fall largely upon Region 1 of the United States Forest Service. Region 1 has to compete with nine other regions of the Forest Service, each of which has its slight or great fire-problem and each of which demands "its share" of the total fire-control funds appropriated annually to the Forest Service for the country as a whole. No region as yet receives as much money for fire-control as it believes is needed to do a good job of protection. Consequently there is continual debate and argument between regions, each demanding more funds for "its share."

Obviously, if there is any difference between the runoff from snow-melt in green-forested, partly burned, or completely devastated headwaters, the distance at which forecasts are definitely applicable is one factor to be considered in allocating the limited, country-wide, fire-control funds among National Forest Regions, and among National Forests within a region. That forest or region whose snow-courses serve as a basis for predictions of runoff or stream-flow over the largest area should receive a larger proportion of fire-control funds than other regions of otherwise similar fire-protection problems.

Many other factors such as applied value of the stream-forecasts must, of course, be considered, because forecasts used by owners of property worth only $50,000 within 50 miles of the snow-course would not compare with forecasts, or forest-protection needs at the headwaters, for a stream completely utilized within 25 miles on property worth $500,000.

The principle seems already recognized that those snow-courses useful in predicting stream-flow of the most used or the most dangerous streams are most worth installation and operation. The "limit of practicable usefulness" of such courses and surveys has not been reached, however, until the value of each course, based on use at all localities, even those "quite removed" from the course, has been determined, and that value used in guiding the allotment of fire-control funds for protection of the forest.

Senior Silviculturist, In Charge of Division of Forest Protection,
Northern Rocky Mountain Forest and Range Experiment Station,
Missoula, Montana

## SMALLER WATERSHEDS

J. P. Bonner

The construction of the relationship between snow-cover and runoff is indirectly based on the premise that the data secured from the snow-surveys represent a definite and stable relation to the average precipitation over the watershed under consideration. Unless this requirement is fulfilled, the practicable usefulness of snow-surveys as used to predict runoff is greatly reduced.

The foregoing requirement is particularly applicable to an investigation of runoff from smaller watersheds which have a considerable portion of their drainage-areas at lower elevations with unlike conditions of precipitation than exist at the snow-survey location. The criteria of runoff may become a function of many variables which completely overshadow the snow-cover at higher elevations such as intensity of rainfall, rapidity of snow-melt, effect of antecedent precipitation on soil-moisture, the height of the ground-water table, and many others.

Because of the urgent need for information not only as to amount but also as to rate of runoff caused by rains or melting snows of various intensities, it appears desirable to modify the existing snow-survey program to include those areas of lower elevation which bear no relation to the information obtained in the headwater-regions. The Soil Conservation Service and other agencies are vitally concerned with the rational planning of water-conservation and flood-control structures on small watersheds where little if any information is available. Snow-survey data become an integral part of any intelligent design.

Snow-courses have been located at various points in the States of Idaho, Washington, and Oregon to secure information which would not be available from the courses in remote areas. The procedure to be employed follows the same general pattern of the work at higher elevations, with the exception that these courses are to be run at more frequent intervals so that for each period of runoff the quantity of moisture in the form of snow is available.

It is hoped that this additional information may increase the practicable usefulness of the snow-surveys made in the headwater-regions or, at least, furnish a factual basis for some of the variables which enter into the prediction of runoff from snow-surveys.

Associate Hydraulic Engineer,
U. S. Soil Conservation Service,
Moscow, Idaho

## CORRELATION OF HEADWATER-STREAMS OF NORTH CONTINENTAL DIVIDE

O. W. Monson

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The popular demand for advance information concerning the flow of streams at critical points along their courses, especially during times of critical flow, has imposed on the forecasting engineer the necessity of using all available data which may have value upon which to base his estimates. Therefore, when the remarkable degree of correlation existing between the water-content of the snow-cover on a particular watershed (at the end of the season of accumulation) and the runoff from the watershed during the four- or five-month runoff-season was discovered, it was only natural that attempts would be made to use this information as widely as possible. Snow-surveys are now used as the basis for stream-flow estimates in connection with flood-control hundreds of miles away, and also for water-supply estimates in irrigated valleys at great distances from the location where the water-content measurements were made.

Snow-surveys, as an index to volume of runoff, are most reliable on the high watersheds where a season of accumulation is followed by a season of runoff. During the season of accumulation, the precipitation is mostly, if not all, in the form of snow which accumulates in a snow-blanket and is later melted or released during the summer runoff-season with a peak-flow in May or June.

These conditions are not found at low altitudes where there is comparatively little storage in the form of snow. Runoff takes place during the thawing periods in winter and after each storm in summer. Therefore, for the large rivers in the Great Plains, forecasts based on snow-surveys can be relied upon only about in the proportion that the runoff from high watersheds bears to the total.

In the mountainous areas, the difficulty of establishing snow-courses in representative areas with a fair degree of assurance for continuous and regular measurements makes it desirable also to stretch the usefulness of available data as far as possible; so the "water-content" measurements in one watershed are often used as a basis for forecast in adjacent or similar drainage-basins.

A measure of the dependability of using snow-survey data from a given snow-course for forecasts of stream-flow at distant points may be obtained by calculating the correlation-coefficient between the water-content of the snow-cover on a given watershed and the runoff at various points downstream. If the water-content be represented by the independent variable x and the summer runoff in acre-feet by the dependent variable y, the degree of correlation may be expressed by the equation

$$r_{xy} = [\Sigma xy - nm_x m_y]/\sqrt{[\Sigma x^2 - n(m_x)^2]\,[\Sigma y^2 - n(m_y)^2]}$$

$r_{xy}$ is called the coefficient of correlation. Its value varies from -1 to +1. A coefficient -1 indicates that large values for the independent variable produce, or correspond to, small values in the dependent variable; while a coefficient +1 indicates that large values for the independent variable produce correspondingly large values in the dependent variable. A coefficient approaching zero indicates that no relation or regularity exists between the two variables being compared.

When this test was applied to the use of water-content measurements on the Jackson Lake Snow-Survey in the Upper Snake River Basin and on the Swift Current Snow-Survey in the St. Mary Drainage-Basin for forecasting stream-flow at distant points, some interesting results were observed.

Jackson Lake Watershed snow-surveys include nine snow-courses, ranging in elevation from 6780 to 7900 feet above sea-level, with an average of 7210 feet. Water-content measurements are made on these snow-courses during the months of January through April of each year, between the 14th and the 21st of each month. Records are available for water-content measurements on Jackson Lake Watershed from 1919 to 1938, but runoff-data for 1937 and 1938 were not available; so only the 18-year period, 1919 through 1936, was used in this study.

Using the coefficient of correlation $r_{xy}$ as the measure of relation, the water-content of the snow-cover on Jackson Lake Watershed was correlated with: (1) Snake River at Moran (corrected for storage in Jackson Lake); (2) Henry's Fork at Warm River; (3) Warm River at Warm River; (4) Tower Creek at Tower Falls; (5) Lamar River at Tower Falls; (6) Gardiner River at Mammoth; (7) Yellowstone River at Canyon; (8) Yellowstone River at Corwin Springs; (9) Yellowstone River at Glendive; (10) Madison River at West Yellowstone; (11) Cark Fork at Chance, Wyoming; and (12) Big Horn River at Thermopolis. As would be expected, the highest degree of correlation was found to exist between the water-content and the runoff from the same watershed; while the discharge at distant points, or the runoff from watersheds of different topographic features, bore comparatively little relation to the water-content measurements.

Table 1 gives the values obtained for $r_{xy}$ for the 12 points listed above, at which comparisons were made.

It is interesting to note the high degree of correlation existing between the runoff from Gardiner River at Mammoth and the water-content in Jackson Lake Watershed. It is only a little less than that existing between the water-content and the runoff in Jackson Lake Basin itself (0.78 as compared with 0.81). A fairly high correlation was observed for Henry's Fork at Warm River, for Warm River at Warm River, and for Yellowstone River at Corwin Springs.

When applied to drainage-basins with runoff-characteristics differing greatly from the one in which the snow-surveys are located, it is only to be expected that the degree of correlation would become smaller. This accounts for 0.47 of Lamar River. At points a long way downstream the runoff is influenced more and more from tributary basins and from diversions and controls; hence, it is not surprising that the correlation of water-content to runoff should be adversely affected. This explains the small coefficient of 0.31 of the Yellowstone at Glendive and 0.28 of the Big Horn at Thermopolis.

On the Swift Current Watershed another fairly long record of water-content measurements is available for study. Snow-surveys were established in Swift Current Basin in 1922 and have been continued ever since, thus making a record of 17 years available. Only the period 1922-36 has been used, however, for the reason previously explained. The Swift Current Snow-Survey consists

Table 1--Values of correlation-coefficient, $r_{xy}$

| No. | Place | Period of record | $r_{xy}$ |
|---|---|---|---|
| 1 | Snake River at Moran, storage in Jackson Lake | May 1 to September 30, 1919-36, 18-year period | 0.81 |
| 2 | Henry's Fork at Warm River | May 1 to September 30, 1919-32, 14-year period | 0.73 |
| 3 | Warm River at Warm River | May 1 to September 30, 1919-32, 14-year period | 0.74 |
| 4 | Tower Creek at Tower Falls | May 1 to September 30, 1923-36, 14-year period | 0.66 |
| 5 | Lamar River at Tower Falls | May 1 to September 30, 1923-36, 14-year period | 0.47 |
| 6 | Gardiner River at Mammoth | May 1 to September 30, 1923-36, 14-year period | 0.78 |
| 7 | Yellowstone River at Canyon | June 1 to September 30, 1921-36, 16-year period | 0.68 |
| 8 | Yellowstone River at Corwin Springs | May 1 to September 30, 1919-32, 14-year period | 0.76 |
| 9 | Yellowstone River at Glendive | May 1 to September 30, 1919-32, 14-year period | 0.31 |
| 10 | Madison River at West Yellowstone | May 1 to September 30, 1919-36, 18-year period | 0.60 |
| 11 | Clark Fork at Chance, Wyoming | May 1 to September 30, 1921-36, 16-year period | 0.62 |
| 12 | Big Horn River at Thermopolis | May 1 to September 30, 1919-36, 18-year period | 0.28 |

of seven snow-courses in Swift Current Basin, having an average elevation of 6000 feet. Water-content measurements are made about May 1 of each year.

For this study, correlation-coefficients were calculated between the water-content in Swift Current Basin and runoff at the following points, with results as given in Table 2.

Table 2--Values of correlation-coefficient, $r_{xy}$

| No. | Place | Period of record | $r_{xy}$ |
|---|---|---|---|
| 1 | Swift Current Creek at Many Glaciers | May 1 to September 30, 1922-36, 15-year period | 0.85 |
| 2 | Flathead River near Polson | May 1 to September 30, 1922-36, 15-year period | 0.87 |
| 3 | Flathead River at Plains, Montana | May 1 to September 30, 1922-36, 15-year period | 0.84 |
| 4 | Marias River near Shelby | May 1 to September 30, 1922-26, 1928, 1931-32, 1934-36, 12-year period | 0.75 |
| 5 | Marias River near Brinkman | May 1 to September 30, 1922-26, 1928, 1931-32, 1934-36, 12-year period | 0.59 |
| 6 | South Fork of Milk River at International Boundary | May 1 to September 30, 1922-36, 15-year period | 0.39 |
| 7 | North Fork of Milk River at International Boundary | May 1 to September 30, 1922-36, 15-year period | 0.20 |

The correlation between water-content and runoff on the Swift Current Watershed is higher than that observed on the Jackson Lake Watershed and a remarkable correlation exists with the runoff from the Flathead River at Polson, and also at Plains. This is particularly interesting inasmuch as the runoff at Polson is drawn from a drainage-area of over 7000 square miles, and at Plains of nearly 20,000 square miles.

In conclusion, it may be said that the limit of practical usefulness of snow-surveys when used to forecast runoff at points a great distance away may safely be determined only by a cut-and-try method of experimentation.

Table 3--Water-content of snow-cover on Jackson Lake Watershed with corrections for precipitation during previous October, for precipitation during October and November, and for low-water flow of Snake River at Moran, with runoff in acre-feet of Snake River near Moran

| Year | Water-content Jackson Lake Watershed | Water-content plus October precipitation at Moran | Water-content plus October and November precipitation at Moran | Water-content plus ten times October runoff, Snake River | Runoff, Snake River at Moran, May 1-Sept. 30 |
|---|---|---|---|---|---|
| | inches | inches | inches | inches | acre-feet |
| 1919 | 18.4 | 20.13 | 21.13 | 28.7 | 457,230 |
| 1920 | 23.0 | 25.58 | 27.38 | 29.0 | 796,390 |
| 1921 | 21.3 | 22.77 | 24.59 | 30.4 | 843,960 |
| 1922 | 23.4 | 24.10 | 27.70 | 26.8 | 807,080 |
| 1923 | 23.0 | 23.77 | 24.54 | 27.7 | 758,450 |
| 1924 | 17.7 | 19.32 | 20.18 | 24.4 | 463,830 |
| 1925 | 21.9 | 27.10 | 28.36 | 31.5 | 1,058,550 |
| 1926 | 15.6 | 17.09 | 18.19 | 21.2 | 510,790 |
| 1927 | 36.0 | 37.75 | 43.54 | 42.5 | 1,179,340 |
| 1928 | 31.5 | 32.36 | 36.88 | 40.3 | 1,037,300 |
| 1929 | 22.0 | 23.72 | 24.82 | 28.9 | 657,300 |
| 1930 | 11.7 | 12.67 | 13.34 | 16.7 | 585,360 |
| 1931 | 8.9 | 12.38 | 13.32 | 18.9 | 389,040 |
| 1932 | 25.0 | 26.82 | 27.78 | 30.0 | 799,800 |
| 1933 | 24.0 | 25.06 | 26.58 | 28.5 | 704,710 |
| 1934 | 15.7 | 15.91 | 16.37 | 20.3 | 378,650 |
| 1935 | 23.8 | 26.61 | 28.70 | 30.1 | 724,640 |
| 1936 | 32.0 | 32.65 | 34.33 | 37.0 | 778,140 |

Table 4--Water-content of snow-cover in Jackson Lake Watershed with corrections for precipitation at Lake Station during October and for runoff from Yellowstone River at Canyon during October

| Year | Water-content of snow-cover, Jackson Lake Watershed | Water-content plus October precipitation at Lake Station | Water-content plus October runoff times ten | Runoff, Yellowstone River near Canyon |
|---|---|---|---|---|
| | inches | inches | inches | acre-feet |
| 1921 | 21.3 | 22.85 | 33.5 | 689,000 |
| 1922 | 23.4 | 23.80 | 31.6 | 634,100 |
| 1923 | 23.0 | 23.05 | 32.5 | 694,500 |
| 1924 | 17.7 | 18.64 | 27.5 | 487,100 |
| 1925 | 21.9 | 23.95 | 30.8 | 1,007,000 |
| 1926 | 15.6 | 17.25 | 25.5 | 467,700 |
| 1927 | 36.0 | 36.11 | 43.9 | 962,000 |
| 1928 | 31.5 | 32.94 | 42.4 | 891,700 |
| 1929 | 22.0 | 22.62 | 32.5 | 533,000 |
| 1930 | 11.7 | 13.56 | 19.8 | 587,400 |
| 1931 | 8.9 | 10.73 | 18.7 | 353,200 |
| 1932 | 25.0 | 25.96 | 29.6 | 693,800 |
| 1933 | 24.0 | 24.65 | 33.6 | 566,200 |
| 1934 | 15.7 | 15.72 | 22.2 | 271,980 |
| 1935 | 23.8 | 25.23 | 28.8 | 641,670 |
| 1936 | 32.0 | 32.70 | 39.8 | 609,440 |

Table 5--Water-content of snow-cover in Swift Current Drainage-Basin 1922-36, with corrections for October precipitation near Babb, for runoff during October of Swift Current Creek, and runoff from Swift Current Creek from May 1 to September 30

| Year | Water-content of snow-cover, Swift Current Basin | Water-content plus October precipitation near Babb | Water-content plus October runoff, Swift Current Creek | Runoff, Swift Current Creek at Many Glaciers, May 1-Sept. 30 |
|---|---|---|---|---|
| | inches | inches | inches | acre-feet |
| 1922 | 22.8 | 22.9 | 25.6 | 57,613 |
| 1923 | 30.9 | 32.0 | 31.9 | 80,520 |
| 1924 | 22.0 | 24.6 | 24.5 | 77,170 |
| 1925 | 34.9 | 35.6 | 36.5 | 104,710 |
| 1926 | 4.1 | 6.9 | 6.3 | 48,040 |
| 1927 | 33.2 | 33.3 | 39.1 | 107,300 |
| 1928 | 37.4 | 38.4 | 43.6 | 102,640 |
| 1929 | 18.1 | 18.8 | 25.6 | 64,860 |
| 1930 | 10.7 | 12.4 | 12.3 | 66,160 |
| 1931 | 12.9 | 13.8 | 14.5 | 68,930 |
| 1932 | 35.6 | 35.9 | 37.2 | 86,470 |
| 1933 | 46.2 | 47.5 | 48.3 | 103,830 |
| 1934 | 28.3 | 30.4 | 35.4 | 81,750 |
| 1935 | 34.2 | 36.2 | 35.9 | 76,780 |
| 1936 | 25.0 | 26.3 | .... | 73,600 |

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## SYMPOSIUM ON EFFECT OF SOIL-PRIMING BY FALL PRECIPITATION ON SPRING RUNOFF

### UPPER SNAKE BASIN

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The experience has been that various procedures are required for different watersheds in order to successfully correlate snow-survey data with runoff. In fact, seldom do two watersheds present identically the same problem in this regard. Among the numerous factors (in addition to the principal one, that is, the amount of water held in storage by snow-cover on mountain snowsheds) which may affect this relationship is the soil-priming influence of fall precipitation. It is the purpose of this paper to test the 20 years' snow-cover survey record for Snake River above Jackson Lake, Wyoming, in this respect. This record is one of the longest and most complete available and is also one which fails, at times, to show the desired very close relationship to runoff. Furthermore, it is expected that fall and spring precipitation influences, to some extent, the runoff from this region.

It should be recognized to begin with that the fault may lie, at least in part, with the snow-cover data. This record is based on surveys on nine courses. The question arises as to whether the snow-cover on these nine courses represents all storm-effects on the watershed. Serious doubt is entertained that they do. Accordingly four additional courses have been added to the present network and eventually snow-data from them may make possible improvement in the best relationship of snow-cover to runoff found so far. The original nine snow-courses extend from north to south boundary of watershed, but lie within the west half of the area. Their elevations range from 6800 to 7900. Westwardly and southwestwardly, directly across the usual path followed by incoming winter storms, Teton Mountain Range rises abruptly to elevations of 10,000 to 12,000 feet. Eastwardly the terrain rises more gradually to closely the same high elevations

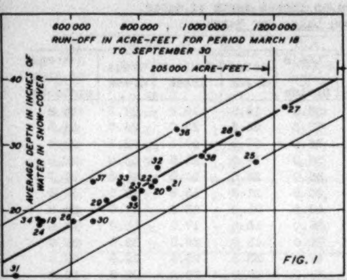

FIG. 1

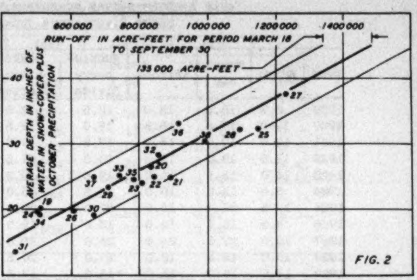

FIG. 2

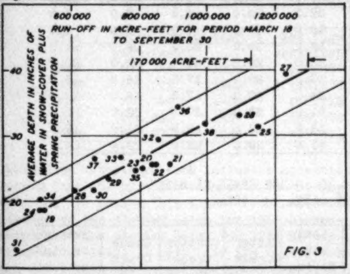

FIG. 3

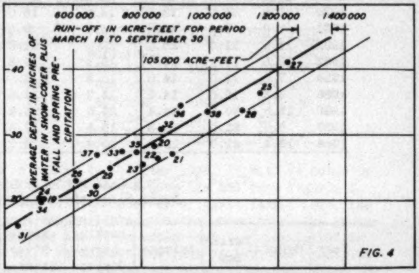

FIG. 4

on the Continental Divide. It is thought that snow on the nine original snow-courses may be, at times, erratically affected by Teton Mountain Range and that snow on the sweep of rising country eastward may be more truly representative of storm-effects. Accordingly the four new courses are located to form an east-west line across the watershed.

The accompanying four curves (Figs. 1, 2, 3, and 4) are designed to show more particularly the influence of rainfall. A somewhat different analysis is made for forecasting the runoff and it should not be construed that these four curves are so employed. Figure 1 is intended to show the relationship which exists between the snow-cover and the runoff. In Figure 2 the fall precipitation which occurs before snow begins to accumulate on the ground is added to the winter's accumulated snowfall. In Figure 3 spring instead of fall rainfall is added, and in Figure 4 both fall and spring rainfall are added.

The nine courses have been regularly surveyed for water-content of snow-cover during the third week of each month from January to April for the past 20 years. The maximum measurement is procured either during the March or the April survey. The best chance to establish a close relationship between the snow-cover and runoff consists, therefore, of using the March snow-data for some years and, for others, the April data--the one which shows the higher water-content of snow-cover. It develops, also, that the precipitation which occurs during the interim between the third week of March and the third week of April should be accounted for if the March snow-cover data are used. Furthermore, the patterns made by plotting the average water-content of the snow on each course separately and by groups show the advantage of using the data for all nine courses weighted exactly alike. Thus the values adopted for snow-cover in the four accompanying curves consist of the average of the nine average maximum water-contents for the nine courses, with the precipitation during March 18 to April 18 added in event the maximum water-content is found during the snow-survey of March 14-21.

The flow of "Snake River near Moran, Wyoming," for the period March 18 to September 30 appears to bear the closest relationship to the average maximum water-content of snow-cover, if the proper deductions and additions for storage in Jackson Lake are made. Such is the basis used for evaluating the runoff in the four accompanying Figures.

Table 1--Snow-survey measurements in inches depth of water, Snake River above Jackson Lake, for March

| Year | Moran | Moran Bay | Arizona | Huckleberry Divide | Snake River Station | Lewis Lake Divide | Aster Creek | Coulter Creek | Glade Creek | Average of nine stations |
|---|---|---|---|---|---|---|---|---|---|---|
| 1919 | 8.5 | 15.5 | 13.0 | 13.5 | 15.0 | 36.0 | 16.5 | 16.5 | 17.0 | 16.8 |
| 1920 | 12.0 | 18.5 | 16.5 | 18.0 | 17.5 | 37.5 | 26.5 | 23.0 | 24.0 | 21.5 |
| 1921 | 11.0 | 17.0 | 16.0 | 17.5 | 17.0 | 36.0 | 27.0 | 20.5 | 23.5 | 20.6 |
| 1922 | 11.5 | 18.0 | 18.0 | 20.0 | 21.5 | 36.0 | 28.0 | 21.5 | 23.5 | 22.0 |
| 1923 | 14.0 | 15.5 | 16.0 | 19.5 | 19.0 | 35.0 | 26.0 | 20.0 | 21.5 | 20.7 |
| 1924 | 8.0 | 15.0 | 10.0 | 13.5 | 15.0 | 26.5 | 21.0 | 15.5 | 18.0 | 15.8 |
| 1925 | 13.5 | 23.0 | 19.0 | 22.0 | 22.0 | 48.5 | 35.0 | 23.5 | 27.0 | 25.9 |
| 1926 | 8.5 | 15.5 | 12.5 | 13.0 | 15.0 | 35.0 | 16.5 | 17.0 | 16.0 | 16.6 |
| 1927 | 15.0 | 27.0 | 24.0 | 26.0 | 28.0 | 72.0 | 45.0 | 28.0 | 32.0 | 33.0 |
| 1928 | 10.0 | 19.5 | 18.0 | 20.0 | 20.5 | 47.0 | 33.5 | 23.5 | 22.0 | 23.8 |
| 1929 | 11.5 | 18.0 | 15.0 | 18.0 | 17.5 | 33.0 | 27.0 | 20.0 | 22.0 | 20.2 |
| 1930 | 8.5 | 15.0 | 12.5 | 14.0 | 15.0 | 32.0 | 22.0 | 16.0 | 16.0 | 16.8 |
| 1931 | 5.0 | 7.5 | 6.5 | 8.0 | 7.0 | 13.0 | 12.0 | 8.0 | 8.5 | 8.4 |
| 1932 | 12.5 | 21.0 | 20.5 | 22.0 | 21.0 | 42.0 | 30.0 | 23.0 | 24.0 | 24.0 |
| 1933 | 12.5 | 17.0 | 17.0 | 18.5 | 20.5 | 36.0 | 29.5 | 21.5 | 22.0 | 21.6 |
| 1934 | 7.0 | 12.0 | 14.0 | 13.5 | 13.5 | 26.0 | 20.0 | 17.0 | 14.5 | 15.3 |
| 1935 | 9.5 | 15.0 | 14.0 | 16.0 | 15.5 | 33.0 | 23.0 | 17.5 | 18.0 | 17.9 |
| 1936 | 16.5 | 30.0 | 24.4 | 25.0 | 25.9 | 51.0 | 37.0 | 27.5 | 32.0 | 29.9 |
| 1937 | 9.0 | 21.0 | 15.5 | 16.4 | 17.0 | 33.5 | 23.5 | 19.9 | 21.8 | 19.7 |
| 1938 | 10.4 | 21.0 | 18.2 | 19.8 | 18.1 | 40.5 | 29.5 | 22.0 | 23.4 | 22.5 |

Table 2--Snow-survey measurements in inches depth of water, Snake River above Jackson Lake, for April

| Year | Moran | Moran Bay | Arizona | Huckleberry Divide | Snake River Station | Lewis Lake Divide | Aster Creek | Coulter Creek | Glade Creek | Average of nine stations |
|---|---|---|---|---|---|---|---|---|---|---|
| 1919 | 10.0 | 17.0 | 13.0 | 15.0 | 15.0 | 37.0 | 21.5 | 18.0 | 19.0 | 18.4 |
| 1920 | 13.5 | 20.5 | 18.5 | 21.5 | 21.5 | 39.0 | 25.0 | 22.5 | 24.5 | 23.0 |
| 1921 | 6.4 | 13.0 | 13.0 | 13.5 | 15.5 | 49.0 | 31.5 | 22.0 | 28.0 | 21.3 |
| 1922 | 12.0 | 19.0 | 15.5 | 19.5 | 20.0 | 42.0 | 30.0 | 22.0 | 30.5 | 23.4 |
| 1923 | 14.5 | 18.5 | 18.0 | 20.0 | 20.0 | 43.0 | 28.0 | 21.0 | 24.0 | 23.0 |
| 1924 | 10.0 | 16.5 | 10.0 | 16.0 | 17.0 | 32.0 | 22.0 | 17.0 | 19.0 | 17.7 |
| 1925 | 7.0 | 19.0 | 13.0 | 19.0 | 16.5 | 47.5 | 30.0 | 18.0 | 27.0 | 21.9 |
| 1926 | 4.5 | 17.0 | 9.0 | 13.0 | 12.0 | 38.0 | 18.0 | 14.0 | 15.0 | 15.6 |
| 1927 | 16.0 | 31.0 | 25.0 | 28.0 | 30.0 | 76.0 | 49.0 | 32.0 | 36.0 | 36.0 |
| 1928 | 15.0 | 27.0 | 21.5 | 23.5 | 28.0 | 60.0 | 46.5 | 28.0 | 34.0 | 31.5 |
| 1929 | 12.5 | 20.0 | 17.0 | 19.0 | 19.5 | 36.0 | 27.0 | 20.0 | 24.0 | 22.0 |
| 1930 | 0 | 10.5 | 8.0 | 10.0 | 9.0 | 24.0 | 22.5 | 11.0 | 10.0 | 11.7 |
| 1931 | 0 | 8.0 | 6.0 | 8.0 | 7.0 | 17.0 | 17.5 | 8.0 | 9.0 | 8.9 |
| 1932 | 10.0 | 20.0 | 19.0 | 25.0 | 22.0 | 45.0 | 33.0 | 26.0 | 25.0 | 25.0 |
| 1933 | 13.0 | 20.0 | 18.0 | 19.5 | 22.5 | 41.5 | 34.5 | 24.5 | 22.5 | 24.0 |
| 1934 | (Est.)0 | 10.0 | 11.5 | 12.0 | 12.0 | 35.5 | 24.0 | 20.0 | 16.5 | 15.7 |
| 1935 | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| 1936 | 16.0 | 37.5 | 25.5 | 27.0 | 27.0 | 55.0 | 40.0 | 28.0 | 32.0 | 32.0 |
| 1937 | 10.5 | 25.5 | 20.0 | 21.2 | 21.5 | 43.0 | 30.0 | 23.5 | 23.8 | 24.3 |
| 1938 | 9.0 | 25.0 | 22.6 | 25.0 | 22.5 | 52.5 | 37.6 | 27.6 | 27.1 | 27.7 |

The Weather Bureau precipitation-station at Moran, Wyoming, is the only one in the area for which records are complete for the past 20 years. It is located at the lowest elevation in the drainage. It happens that this station is also the site of one of the nine snow-courses and, judging from variations in snow-cover which occur from year to year at this point compared to that at the other eight courses, this precipitation-record may not be ideal for supplementing the snow-survey data. Its use in various ways has led to the conclusion that the rainfall during October serves best to correct for the possible fall soil-priming effect.

It will be noted from Figures 1 and 2 that some of the individual plotted points assume more acceptable positions when the precipitation at Moran during October is added to the maximum water-content of snow-cover which occurs during the succeeding month of March or April. As an

Table 3--Precipitation at Moran, Wyoming, 1918-38

| Year | April | May | Oct. | Year | April | May | Oct. |
|---|---|---|---|---|---|---|---|
| | inches | inches | inches | | inches | inches | inches |
| 1918 | .... | .... | 1.73 | 1929 | 1.48 | 0.78 | 0.97 |
| 1919 | 0.35 | 0.07 | 2.58 | 1930 | 1.78 | 1.93 | 3.48 |
| 1920 | 2.94 | 1.25 | 1.47 | 1931 | 1.76 | 1.62 | 1.82 |
| 1921 | 0.85 | 1.43 | 0.70 | 1932 | 1.11 | 1.82 | 1.06 |
| 1922 | 0.84 | 1.22 | 0.77 | 1933 | 1.82 | 2.37 | 0.21 |
| 1923 | 2.37 | 1.66 | 1.62 | 1934 | 1.36 | 0.40 | 2.81 |
| 1924 | 1.27 | 0.41 | 5.20 | 1935 | 2.61 | 2.34 | 0.65 |
| 1925 | 2.37 | 2.73 | 1.49 | 1936 | 1.78 | 1.03 | 0.74 |
| 1926 | 2.53 | 2.32 | 1.75 | 1937 | 3.96 | 0.92 | 2.04 |
| 1927 | 1.30 | 3.27 | 0.86 | 1938 | 1.12 | 3.14 | |
| 1928 | 2.75 | 1.14 | 1.72 | | | | |

Table 4--Net flow of "Snake River near Moran, Wyoming," March 18 to September 30

| Year | Net flow | Year | Net flow | Year | Net flow | Year | Net flow |
|---|---|---|---|---|---|---|---|
| | acre-feet | | acre-feet | | acre-feet | | acre-feet |
| 1919 | 514,144 | 1924 | 504,321 | 1929 | 706,186 | 1934 | 506,968 |
| 1920 | 838,002 | 1925 | 1,145,075 | 1930 | 664,760 | 1935 | 784,803 |
| 1921 | 890,824 | 1926 | 605,729 | 1931 | 439,652 | 1936 | 911,138 |
| 1922 | 844,892 | 1927 | 1,229,378 | 1932 | 857,842 | 1937 | 663,000 |
| 1923 | 802,272 | 1928 | 1,097,211 | 1933 | 740,792 | 1938 | 993,440 |

outstanding example of such influence attention is called to the year 1925. It will be noted in Table 3 that the precipitation at Moran during October 1924 was 5.2 inches and from Figures 1 and 2 that by adding this water to the water-content of snow-cover as of April 14-21, 1925, the position of the plotted point for 1925 becomes more reconcilable. On the other hand, the inconsistency of the plotted point for 1936 is not improved and it is known that fall precipitation accounts, at least in part, for its faulty position. Throughout the fall of 1935 the precipitation was much below normal and snow-cover did not begin to accumulate materially until after the first of the year. A reasonable explanation for this failure is that the precipitation during October 1935 alone does not fully reflect the condition and neither could the snow-cover as it was non-existent throughout the period. The latter condition is unusual for that section and, therefore, it appears to be impossible to apply the fall precipitation for all years alike.

The conclusion may be drawn from this attempt to account for the fall-priming influence of fall precipitation that precipitation-records will not always serve the purpose. It appears reasonable to expect that ground-water measurements at carefully selected points, or collecting pans or gages arranged to determine the depth of water which enters the soil, or soil-moisture determinations will provide the information needed for this purpose.

It may be of further interest to note from Figures 3 and 4 the further possible influence that spring precipitation has on runoff.

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## DISCUSSION

**H. T. GISBORNE**--Regarding the desirability of getting soil-moisture samples at the time of measuring snow-courses, in the course of our fire-research measurements we make soil-moisture determinations at 2300, 2700, 3800, and 5500 feet every ten days from April 1 to October 31. These data might show soil-conditions previous to the beginning of the annual snow-mantle and immediately following. If desired, we can determine soil-moistures beneath the snow the first of January, February, March, April, and May at our two Benton Creek snow-courses at 2300 and 4800 feet in the Priest River Experimental Forest.

Concerning the relationship between snow-depths on April 1 and the character of the following fire-season, our records fail to show any dependable indices. The character of the July and August fire-season seems to be entirely independent of the preceding snow-depths. No study has been made of the relation between snow-moisture and subsequent fire-danger.

JAMES C. MARR--(1) Snow and dust--The condition of soil which underlaid the snow-cover in the Snake Basin during the spring of 1936 was extraordinarily dry. Numerous reports from snow-surveyors carried the statement that the snow was underlaid by dust. A report from lumbering interests stated that their trucks and tractors churned the snow and underlying dust into a light, fluffy mass which made their operations most difficult. The winter was characterized by exceedingly cold temperatures. The resulting runoff proved disappointing, even though snow-cover was discounted in formulating runoff forecasts. In all instances our plotted points for 1936 fall left of our curve.

(2) Lynn Crandall has three zones of snow-conditions--When the average snow-depths for Snake River above Jackson Lake are plotted against runoff for the past 20 years of record, they fall in a wide strip. During past years Lynn Crandall has been using three curves: One a median through all points; one a median through the points which fall to the left of the center curve; and one a median through the points which fall to the right of the center curve. He attempted to select one of these curves in accordance with the climatic conditions which prevailed during the current year.

(3) Each watershed is a problem itself--We are now attempting to prepare a better curve--one which will be consistent for all years, by correcting the plotted points for fall and spring precipitation at Moran, Wyoming. The fall precipitation is much the most important factor and would, we believe, bring all points for all years close to a median curve if the snow-cover started to accumulate at the same time during the fall of all years. The difficulty lies in the fact that the date when snow falls and remains on the ground varies. We find that the precipitation during the month of October added to the water-content of snow-cover in April gives very good results for the majority of years. Occasionally, however, when snow starts to accumulate very late in the fall there should be added the precipitation for a longer period. This fact makes it impossible for us to treat data for all years alike. Also, we lack information as to the date when the snow begins to accumulate. We construe this circumstance as a drawback in the use of precipitation-data for correcting our correlations of snow-cover and runoff. It is thought that fall stream-flow records, the flow of springs, ground-water levels, or soil-moisture determinations might be a better basis for correcting the snow-cover runoff relationship.

We do not have this difficulty in the Boise Basin for the reason that fall and spring precipitation appear to affect runoff very little.

O. W. MONSON--The October runoff may not represent soil-drainage, because of the weather-conditions that time of the year. Sometimes we have rather a prolonged rainy season during October here in the valleys. During the same time, it is supposed that we get snow in the mountains, which will begin to accumulate during the winter, though this is not always true. I have known considerable muddy water to come out of the mountains as late as October.

J. E. CHURCH--On the trip by bus southward from Spokane to Walla Walla after the meeting, a favorable opportunity was afforded of observing the water-condition of the soil. Unquestionably autumn priming in the Northwest has a positive effect on spring runoff there because autumn rainfall is heavy. However, this problem has little prominence in the region farther south where autumn rainfall is relatively light, as in Nevada and probably in Utah.

## ANALYSIS OF SNOW-COVER AND RUNOFF IN UPPER SNAKE, UPPER YELLOWSTONE, AND SWIFT CURRENT WATERSHEDS

O. W. Monson

(Contribution from Montana Agricultural Experiment Station, Journal No. 121)

In the use of snow-survey data, particularly water-content measurements, as a basis for estimating or predicting the runoff from a given watershed, it has long been recognized that other factors enter in which disturb the relationship that appears to exist between the amount of water stored in the snow-blanket at the end of winter and the amount of runoff which occurs during the spring and summer months or runoff-season.

Among the factors which affect the correlation between water-content and runoff, the following are considered important: (1) Precipitation on the watershed during the runoff-period; (2) evaporation and transpiration-losses from the watershed, including evaporation or sublimation from the snow-cover itself; (3) ground-storage, as reflected by the fluctuations in water-table caused by draining and recharging of the ground-water reservoir; and (4) deep percolation-losses that is, drainage through deep subterranean channels which does not appear again as springs tributary to the stream in question.

The engineer is faced with the problem of making corrections for these factors, although but very little basic information with which to work is available. Precipitation-records are seldom available for the high watersheds where water-content measurements are made. The water-content of the snow-cover can not be taken as the measure of total precipitation during the winter because of evaporation or sublimation from the snow-cover, as well as interception of snowfall by trees. To make correction for summer precipitation, one would need to be able to predict the amount before its actual occurrence.

Evaporation- and transpiration-losses from the watershed during the runoff-season are likewise more or less indeterminate; since they vary with the temperature, precipitation, kind and amount of vegetative cover, over-grazing, etc., all of which are variable and very difficult to measure. Also, if consideration is to be given to them it would be necessary to predict their occurrence several months in advance. This is, itself, impossible so far as our knowledge extends at present.

The third factor, that of ground-storage or watershed-priming, may be approached in a number of ways; although here again experimental data are limited but not entirely lacking.

Observation-wells would seem to be a logical means of measuring the fluctuation in the water-table, but when an attempt is made to locate and establish such wells, several difficulties immediately arise. First of these is the location and distribution of observation-wells. The soil-mantle is very uneven on the high watersheds, ranging from 100 feet or more of alluvium in places to just a few inches of decomposed rock and leaf-mold in others. The water-table varies accordingly. The use of ground-water levels as a basis for the watershed priming factor will require several seasons of water-records. Since these are not available, it will be necessary first to locate a rather extensive system of observation-wells and, second, to keep records of these several years before any conclusions can be drawn.

Collecting pans or gages for measuring the amount of water entering the soil either from rainfall or snow offer even more difficulties than the establishment of observation-wells. Not only would the selection of representative locations be difficult, but the construction would be complicated and expensive.

These two methods, while of little value at present because of the time-factor, offer a field for research which should be both interesting and productive of results

The making of soil-moisture determinations in the fall and spring are helpful in a general way to guide the forecaster in arriving at an estimate regarding the probable yield in runoff from a given watershed. Thus, a dry soil-condition is likely to reduce the percentage of runoff from the snow-cover by at least the amount necessary to prime the soil or saturate it to a degree that percolation and runoff will take place.

The amount of water necessary to "prime" the watershed any particular year will depend upon the degree of saturation which exists at the beginning of the melting season. The amount of water held by the soil-mantle itself represents only a part of the capacity for underground storage. No doubt the greater part is hidden in the crevices and caverns which feed the perennial springs. If the soil is dry when melting begins, the engineer may expect the actual runoff to fall to the left of the regression-line; while if the soil is moist or wet when the water-content measurement is made, the probability is that the runoff will be more than the curve of water-content and runoff indicates.

Two other approaches to the problem of making allowance for watershed-priming will be discussed in greater detail: (1) The consideration of fall precipitation as a measure of watershed-priming; (2) the consideration of low-water flow (largely from perennial springs) in the drainage-basin as an index to the general ground-water conditions.

These tests have been applied to: (1) The Snake River Basin above Moran and the Yellowstone River above Canyon--both based on the Jackson Lake snow-surveys; (2) Swift Current Creek at Many Glaciers--based on the Swift Current snow-survey.

The following values for $r_{xy}$ were obtained when the water-content of snow-cover on Jackson Lake Watershed was used as the basis for estimating runoff from Snake River at Moran and Yellowstone River at Canyon, with fall precipitation and fall runoff, and as a correction-factor for watershed-priming.

Correlations between water-content on Jackson Lake Watershed and runoff from Snake River at Moran and Yellowstone River at Canyon are:

| (1) Runoff from Snake River at Moran | $r_{xy}$ |
|---|---|
| (a) Water-content at Jackson Lake (no correction for priming) | 0.81 |
| (b) Water-content plus previous October precipitation at Moran | 0.84 |
| (c) Water-content plus previous October and November precipitation at Moran | 0.83 |
| (d) Water-content plus October runoff in inches | 0.82 |
| (e) Water-content plus ten times October runoff in inches | 0.88 |
| (2) Runoff from Yellowstone River at Canyon | |
| (a) Water-content at Jackson Lake (no correction for priming) | 0.68 |
| (b) Water-content plus October precipitation at Lake | 0.77 |
| (c) Water-content plus ten times October runoff in inches | 0.69 |

The correlation between the water-content of snow-cover in Swift Current Basin Watershed and runoff from Swift Current Creek is:

| (1) Runoff from Swift Current Creek | $r_{xy}$ |
|---|---|
| (a) Water-content (no correction for watershed-priming), 1922-36 | 0.85 |
| (b) Water-content plus October precipitation at Babb 1922-36 | 0.85 |
| (c) Water-content plus October runoff at Many Glaciers, 1922-35 | 0.83 |
| (d) Water-content (no correction for priming), 1922-35 | 0.86 |

In the case of runoff of the Snake River at Moran, correction by adding the previous October precipitation at Moran to the water-content measured on Jackson Lake Watershed gave a higher coefficient of correlation than when no correction was made. When both October and November precipitation were added to the water-content, the result was less accurate than when only the October precipitation was used as a correction-factor.

When the October runoff in surface-inches was weighted by multiplying by ten, the correlation was highest. The data from which these correlations were calculated are given in Table 1 and are shown graphically in Figures 1-A, 1-B, 1-C, and 1-D. The advantage of correcting for watershed-priming by adding ten times the runoff to the water-content may be seen by comparing Figures 1-A and 1-D, but it is not so noticeable as might be expected.

Table 1--Water-content of snow-cover on Jackson Lake Watershed with corrections for precipitation during previous October, for precipitation during October and November, and for low-water flow of Snake River at Moran, with runoff in acre-feet of Snake River near Moran, 1919-36

| Year | Water-content Jackson Lake Watershed (a) | Water-content plus October precipitation at Moran (b) | Water-content plus October and November precipitation at Moran (c) | Water-content plus ten times October runoff, Snake River (d) | Runoff, Snake River at Moran, May 1-Sept. 1 |
|---|---|---|---|---|---|
| | inches | inches | inches | inches | acre-feet |
| 1919 | 18.4 | 20.13 | 21.13 | 28.7 | 457,230 |
| 1920 | 23.0 | 25.58 | 27.38 | 29.0 | 796,390 |
| 1921 | 21.3 | 22.77 | 24.59 | 30.4 | 843,960 |
| 1922 | 23.4 | 24.10 | 27.70 | 26.8 | 807,080 |
| 1923 | 23.0 | 23.77 | 24.54 | 27.7 | 758,450 |
| 1924 | 17.7 | 19.32 | 20.18 | 24.4 | 463,830 |
| 1925 | 21.9 | 27.10 | 28.36 | 31.5 | 1,058,550 |
| 1926 | 15.6 | 17.09 | 18.19 | 21.2 | 510,790 |
| 1927 | 36.0 | 37.75 | 43.54 | 42.5 | 1,179,340 |
| 1928 | 31.5 | 32.36 | 36.88 | 40.3 | 1,037,300 |
| 1929 | 22.0 | 23.72 | 24.82 | 28.9 | 657,300 |
| 1930 | 11.7 | 12.67 | 13.34 | 16.7 | 585,360 |
| 1931 | 8.9 | 12.38 | 13.32 | 18.9 | 389,040 |
| 1932 | 25.0 | 26.82 | 27.78 | 30.0 | 799,800 |
| 1933 | 24.0 | 25.06 | 26.58 | 28.5 | 704,710 |
| 1934 | 15.7 | 15.91 | 16.37 | 20.3 | 378,650 |
| 1935 | 23.8 | 26.61 | 28.70 | 30.1 | 724,640 |
| 1936 | 32.0 | 32.65 | 34.33 | 37.0 | 778,140 |

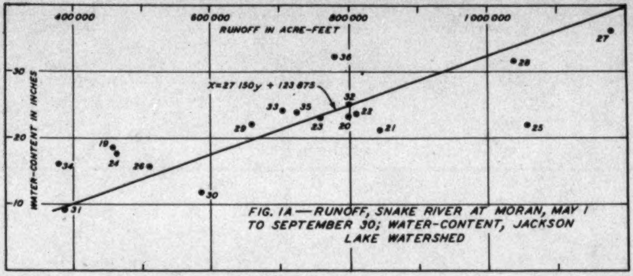

FIG. 1A — RUNOFF, SNAKE RIVER AT MORAN, MAY 1 TO SEPTEMBER 30; WATER-CONTENT, JACKSON LAKE WATERSHED

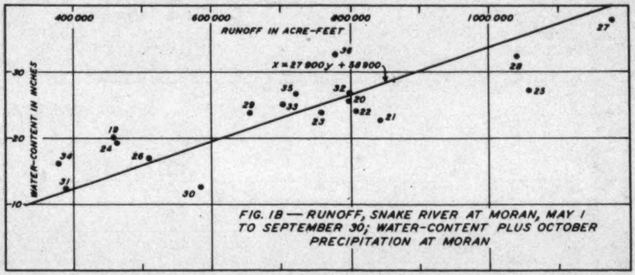

FIG. 1B — RUNOFF, SNAKE RIVER AT MORAN, MAY 1 TO SEPTEMBER 30; WATER-CONTENT PLUS OCTOBER PRECIPITATION AT MORAN

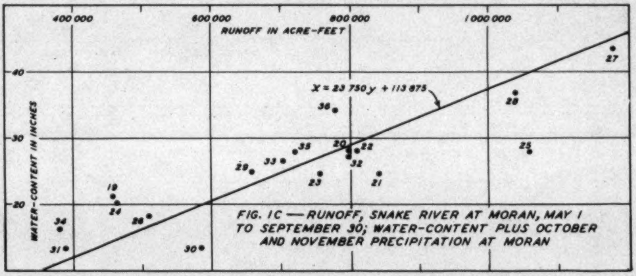

FIG. 1C — RUNOFF, SNAKE RIVER AT MORAN, MAY 1 TO SEPTEMBER 30; WATER-CONTENT PLUS OCTOBER AND NOVEMBER PRECIPITATION AT MORAN

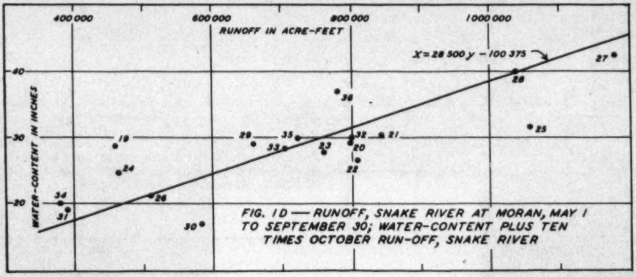

FIG. 1D — RUNOFF, SNAKE RIVER AT MORAN, MAY 1 TO SEPTEMBER 30; WATER-CONTENT PLUS TEN TIMES OCTOBER RUN-OFF, SNAKE RIVER

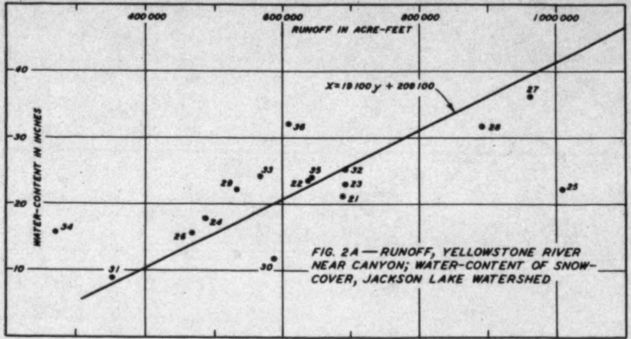

FIG. 2A — RUNOFF, YELLOWSTONE RIVER NEAR CANYON; WATER-CONTENT OF SNOW-COVER, JACKSON LAKE WATERSHED

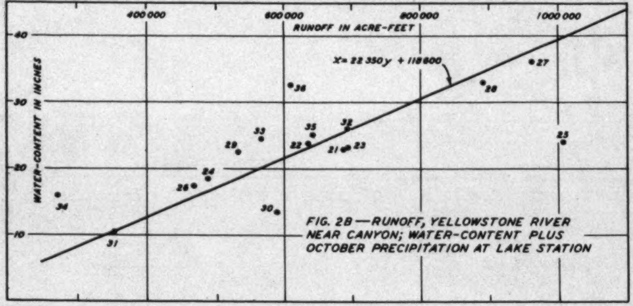

FIG. 2B — RUNOFF, YELLOWSTONE RIVER NEAR CANYON; WATER-CONTENT PLUS OCTOBER PRECIPITATION AT LAKE STATION

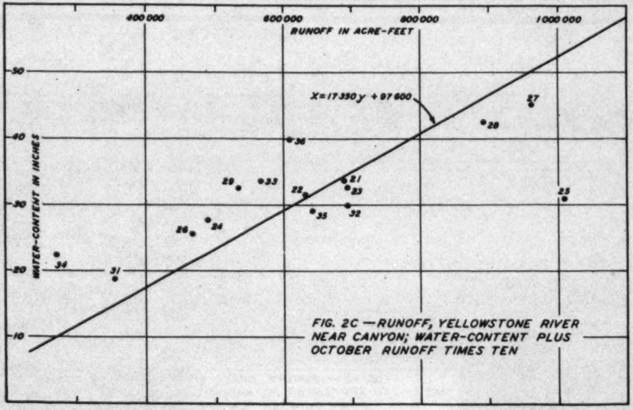

FIG. 2C — RUNOFF, YELLOWSTONE RIVER NEAR CANYON; WATER-CONTENT PLUS OCTOBER RUNOFF TIMES TEN

Table 2--Water-content of snow-cover in Jackson Lake Watershed with corrections for precipitation at Lake Station during October, and for runoff from Yellowstone River at Canyon during October, 1921-36

| Year | Water-content of snow-cover, Jackson Lake Watershed (a) | Water-content plus October precipitation at Lake Station (b) | Water-content plus ten times October runoff (c) | Runoff, Yellowstone River near Canyon |
|---|---|---|---|---|
| | inches | inches | inches | acre-feet |
| 1921 | 21.3 | 22.85 | 33.5 | 689,000 |
| 1922 | 23.4 | 23.80 | 31.6 | 634,100 |
| 1923 | 23.0 | 23.05 | 32.5 | 694,500 |
| 1924 | 17.7 | 18.64 | 27.5 | 487,100 |
| 1925 | 21.9 | 23.95 | 30.8 | 1,007,000 |
| 1926 | 15.6 | 17.25 | 25.5 | 467,700 |
| 1927 | 36.0 | 36.11 | 43.9 | 962,000 |
| 1928 | 31.5 | 32.94 | 42.4 | 891,700 |
| 1929 | 22.0 | 22.62 | 32.5 | 533,000 |
| 1930 | 11.7 | 13.56 | 19.8 | 587,400 |
| 1931 | 8.9 | 10.73 | 18.7 | 353,200 |
| 1932 | 25.0 | 25.96 | 29.6 | 693,800 |
| 1933 | 24.0 | 24.65 | 33.6 | 566,200 |
| 1934 | 15.7 | 15.72 | 22.2 | 271,980 |
| 1935 | 23.8 | 25.23 | 28.8 | 641,670 |
| 1936 | 32.0 | 32.70 | 39.8 | 609,440 |

Table 3--Water-content of snow-cover in Swift Current Drainage-Basin 1922-36, with corrections for October precipitation near Babb, and for runoff during October of Swift Current Creek, with runoff from Swift Current Creek from May 1 to September 30

| Year | Water-content of snow-cover, Swift Current Basin (a) | Water-content plus October precipitation near Babb (b) | Water-content plus October runoff, Swift Current Creek (c) | Runoff, Swift Current Creek at Many Glaciers, May 1-Sept. 30 |
|---|---|---|---|---|
| | inches | inches | inches | acre-feet |
| 1922 | 22.8 | 22.9 | 25.6 | 57,613 |
| 1923 | 30.9 | 32.0 | 31.9 | 80,520 |
| 1924 | 22.0 | 24.6 | 24.5 | 77,170 |
| 1925 | 34.9 | 35.6 | 36.5 | 104,710 |
| 1926 | 4.1 | 6.9 | 6.3 | 48,040 |
| 1927 | 33.2 | 33.3 | 39.1 | 107,300 |
| 1928 | 37.4 | 38.4 | 43.6 | 102,640 |
| 1929 | 18.1 | 18.8 | 25.6 | 64,860 |
| 1930 | 10.7 | 12.4 | 12.3 | 66,160 |
| 1931 | 12.9 | 13.8 | 14.5 | 68,930 |
| 1932 | 35.6 | 35.9 | 37.2 | 86,470 |
| 1933 | 46.2 | 47.5 | 48.3 | 103,830 |
| 1934 | 28.3 | 30.4 | 35.4 | 81,750 |
| 1935 | 34.2 | 36.3 | 35.9 | 76,780 |
| 1936 | 25.0 | 26.3 | .... | 73,600 |

As a check against the correlation-factor, the runoff was calculated from the regression-line obtained by method of least squares and the estimated amount compared with the actual runoff to determine the percentage of error. The average error when no correction-factor was applied was 21 per cent. The average per cent of error when the priming factor for low-water flow was used was 16 per cent. These figures represent averages only and do not mean that all points were brought nearer into line. As a matter of fact, the points for 1919 and 1930 were thrown farther off the line than when no correction was attempted.

For the runoff of Yellowstone River at Canyon, the addition of October precipitation to the water-content improved the correlation about nine points, while using the weighted low-water flow improved it only one point. Apparently methods and technique developed for one watershed

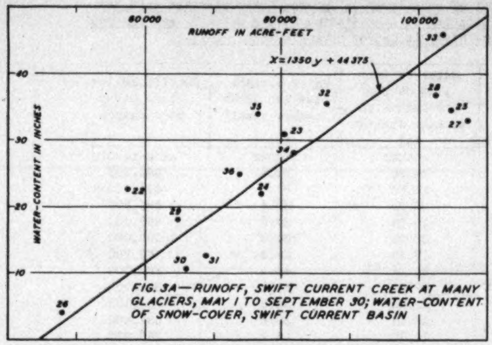

FIG. 3A—RUNOFF, SWIFT CURRENT CREEK AT MANY GLACIERS, MAY 1 TO SEPTEMBER 30; WATER-CONTENT OF SNOW-COVER, SWIFT CURRENT BASIN

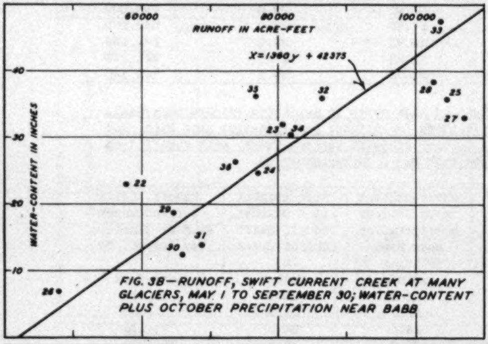

FIG. 3B—RUNOFF, SWIFT CURRENT CREEK AT MANY GLACIERS, MAY 1 TO SEPTEMBER 30; WATER-CONTENT PLUS OCTOBER PRECIPITATION NEAR BABB

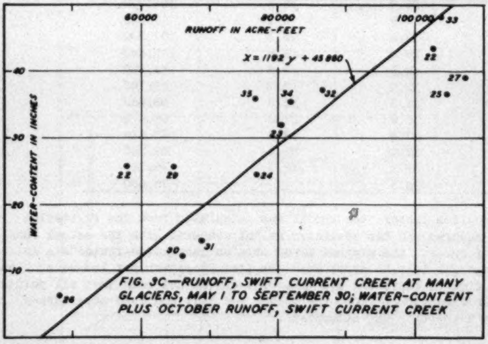

FIG. 3C—RUNOFF, SWIFT CURRENT CREEK AT MANY GLACIERS, MAY 1 TO SEPTEMBER 30; WATER-CONTENT PLUS OCTOBER RUNOFF, SWIFT CURRENT CREEK

can not be depended upon for others. The data showing the relations of water-content to runoff on Jackson Lake Watershed above Moran are given in Table 2 and are illustrated in Figures 2-A, 2-B, and 2-C.

The application of the correlation-test to the Swift Current snow-surveys showed no positive effect when a correction-factor was used for watershed-priming. When the October precipitation at Babb (the nearest weather-station) was added to the water-content, the value of $r_{xy}$ was exactly the same as when no correction-factor was used.

When the low-water, or October, runoff from Swift Current Basin was used as an index to the ground-water conditions on the watershed, a negative result was obtained. The value of $r_{xy}$ was 0.83 as compared with 0.86 when no correction was made over the same period of record.

The data covering water-content and runoff from Swift Current Basin are given in Table 3. They are shown graphically in Figures 3-A, 3-B, and 3-C. It appears, from these, that the correlation is not improved by either of the attempts at correction for watershed-priming. The deviations from the regression-line calculated by the method of least squares are nearly the same when an attempt is made to correct for watershed-priming as when no correction is made. Indeed, when the October runoff is added, the points are more scattered than if no correction is made.

It is clear that neither the previous October precipitation at Babb, which is assumed to be proportional to that which occurs on Swift Current Watershed, nor the runoff from Swift Current Creek at Many Glaciers, which is assumed to reflect the ground-water conditions on the watershed, explain why the runoff in 1922 and 1935 was so much less than expected from the water-content measurement nor why the runoff during 1925-27 was so much greater than expected.

Some other reason must be found for the wide deviation. A study of summer rainfall-conditions may explain why these four years do not conform to average conditions. The amount of rainfall during the runoff-season without doubt has a tendency to disturb the relation of water-content to runoff. The difficulty of allowing for this disturbance lies in the fact that the amount of rainfall occurring during the summer cannot be predicted several months in advance. In 1922 the summer rainfall at Babb during May was about normal, while in June it was only 21 per cent of normal. This may be at least a partial explanation for the wide deviation from the expected runoff.

The heavy runoff during 1925 can not be explained by summer precipitation, judging from conditions recorded at Babb. During May the amount of rainfall was only 17 per cent of normal, and during June it was 92 per cent of normal. Clearly, this does not explain a runoff of 11,000 acre-feet in excess of the estimated amount based on the regression-line.

It is interesting to note that the 1924 runoff was also greater than expected; so it is possible that the watershed was well primed at the close of the 1924 season, making the accumulation of water in the snow more effective, notwithstanding the fact that the previous October runoff was a trifle less than average.

The deviations of 1927 and 1935 were, no doubt, due largely to variation in summer precipitation. In 1927 the May rainfall at Babb was 406 per cent of normal, although June was only 39 per cent. If similar conditions prevailed on the watershed above Many Glaciers during these months, the abnormally high runoff during the 1927 season could logically be expected. In 1935 both May and June precipitation was below normal, and the below-normal runoff from Swift Current Creek may be considered as a natural consequence.

In conclusion, this study shows that consideration of moisture-conditions on the watershed from the standpoint of its being dry or primed when water-content measurements are made may improve the accuracy of estimates in some cases, but can not generally be depended upon to do so. It reaffirms a statement often made: "Each watershed is a law unto itself." It emphasizes also the need for more basic data regarding meteorological and hydrological conditions on the high watersheds--a fact long recognized by engineers but not fully appreciated by laymen, from whom approval of budgets is required.

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## RELATION OF FALL STREAM-FLOW TO SPRING RUNOFF

Henry C. Eagle

(Published with the approval of the Director, U. S. Geological Survey)

In the prediction of spring runoff from precipitation-records or snow-surveys, one of the factors which seems to require consideration is the amount of water held in ground-storage. The determination of the quantity of water in ground-storage is a difficult problem involving soil-sampling, measurements of ground-water wells, and measurements of the flow of small streams and springs. It has occurred to the writer that selected stream-flow records for either the late fall or early spring might provide a better index of the ground-water available for spring runoff than that obtained by other methods. This would involve a comparison of runoff in the fall with runoff in the spring, and might eliminate uncertainties in the relation of a reservoir-level in the fall with runoff in the spring. Such a method would be especially desirable because of the availability of stream-flow records. The discussion which follows is more an explanation of the method to be used than an attempt to develop an accurate formula for the prediction of spring runoff.

The spring runoff for the Yellowstone River at Corwin Springs, Montana, taken from records of the United States Geological Survey from 1911 to 1938, was compared with precipitation at Yellowstone Park, Wyoming, as published by the Weather Bureau. It is recognized that the precipitation at Yellowstone Park may not be representative of the precipitation over the entire drainage-area above Corwin Springs. Further, the precipitation-record is not as satisfactory for predicting runoff as snow-surveys would be if they were available.

Table 1 shows all the base-data which were used, together with the computed values of runoff

Table 1--Precipitation-runoff relations, Yellowstone River at Corwin Springs, Montana, 1911-1938

| Year | Precipitation | | Measured runoff | | Runoff | Computed runoff | | | Error in per cent | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Nov. 1 to Apr. 30 | May 1 to July 31 | October mean[a] | May 1 to July 31 | October mean[a] | From winter precipitation | Corrected by three times October mean | Corrected by six times October mean | Winter precipitation | Corrected by three times October mean | Corrected by six times October mean |
| | inches | inches | s.f. | acre-feet | inches | acre-feet | acre-feet | acre-feet | | | |
| 1911 | 10.4 | 5.4 | 1270 | 1,850,000 | 0.55 | 2,420,000 | 2,030,000 | 1,866,000 | +30.8 | + 9.7 | + 0.9 |
| 1912 | 9.5 | 5.8 | 1650 | 1,380,000 | 0.72 | 2,150,000 | 1,968,000 | 1,884,000 | +55.8 | +42.6 | +36.5 |
| 1913 | 9.1 | 8.0 | 1860 | 1,986,000 | 0.81 | 2,030,000 | 1,928,000 | 1,920,000 | + 3.2 | - 2.9 | - 3.3 |
| 1914 | 6.4 | 4.0 | 1800 | 1,407,000 | 0.78 | 1,220,000 | 1,354,000 | 1,398,000 | -13.3 | - 3.8 | - 0.6 |
| 1915 | 3.6 | 6.1 | 2280 | 942,000 | 0.99 | 480,000 | 923,000 | 1,110,000 | -49.1 | - 2.0 | +17.8 |
| 1916 | 7.7 | 6.5 | 1620 | 1,711,000 | 0.70 | 1,610,000 | 1,579,000 | 1,542,000 | - 5.9 | - 7.7 | - 9.9 |
| 1917 | 10.3 | 3.0 | 1860 | 1,700,000 | 0.81 | 2,390,000 | 2,174,000 | 2,136,000 | +40.6 | +27.9 | +25.6 |
| 1918 | 10.4 | 7.1 | 1990 | 1,930,000 | 0.86 | 2,420,000 | 2,235,000 | 2,208,000 | +25.4 | +15.8 | +14.4 |
| 1919 | 6.0 | 2.2 | 2350 | 776,000 | 1.02 | 1,110,000 | 1,436,000 | 1,578,000 | +43.1 | +85.0 | +103 |
| 1920 | 7.5 | 4.7 | 984 | 1,455,000 | 0.43 | 1,550,000 | 1,374,000 | 1,218,000 | + 6.5 | - 5.6 | -16.3 |
| 1921 | 7.4 | 6.5 | 1670 | 1,508,000 | 0.72 | 1,520,000 | 1,538,000 | 1,524,000 | + 0.8 | + 2.0 | + 1.1 |
| 1922 | 9.2 | 3.1 | 1280 | 1,205,000 | 0,55 | 2,060,000 | 1,784,000 | 1,650,000 | +70.8 | +48.0 | +36.9 |
| 1923 | 7.8 | 4.8 | 1270 | 1,207,000 | 0.55 | 1,640,000 | 1,497,000 | 1,398,000 | +35.9 | +24.0 | +15.8 |
| 1924 | 5.4 | 4.6 | 1480 | 992,000 | 0.64 | 920,000 | 1,066,000 | 1,056,000 | - 7.8 | + 7.5 | + 6.5 |
| 1925 | 9.2 | 6.2 | 1580 | 1,921,000 | 0.68 | 2,060,000 | 1,866,000 | 1,794,000 | + 7.2 | - 2.9 | - 7.1 |
| 1926 | 5.2 | 3.6 | 2010 | 1,096,000 | 0.87 | 860,000 | 1,169,000 | 1,272,000 | -21.5 | + 6.7 | +16.1 |
| 1927 | 7.0 | 4.4 | 1360 | 1,799,000 | 0.59 | 1,400,000 | 1,374,000 | 1,290,000 | -22.2 | -23.6 | -28.3 |
| 1928 | 9.1 | 4.8 | 2100 | 2,049,000 | 0.91 | 2,030,000 | 1,989,000 | 2,028,000 | - 0.9 | - 2.9 | - 1.0 |
| 1929 | 5.8 | 3.5 | 1580 | 1,219,000 | 0.68 | 1,040,000 | 1,169,000 | 1,182,000 | -14.7 | - 4.1 | - 3.0 |
| 1930 | 6.0 | 2.9 | 1290 | 1,118,000 | 0.56 | 1,100,000 | 1,148,000 | 1,092,000 | - 1.6 | + 2.7 | - 2.3 |
| 1931 | 3.5 | 3.6 | 1960 | 847,000 | 0.85 | 350,000 | 820,000 | 948,000 | -58.7 | - 3.2 | +11.9 |
| 1932 | 6.2 | 4.9 | 934 | 1,456,000 | 0.40 | 1,160,000 | 1,087,000 | 948,000 | -20.3 | -25.4 | -34.9 |
| 1933 | 4.7 | 2.4 | 1170 | 1,199,000 | 0.51 | 710,000 | 841,000 | 804,000 | -40.8 | -29.9 | -33.0 |
| 1934 | 4.6 | 4.7 | .... | 751,000 | .... | 680,000 | ......... | ......... | - 9.4 | ..... | ..... |
| 1935 | 6.6 | 2.3 | 949 | 1,304,200 | 0.41 | 1,280,000 | 1,169,000 | 1,038,000 | - 1.9 | -10.3 | -20.5 |
| 1936 | 6.2 | 4.2 | 1120 | 1,332,200 | 0.49 | 1,160,000 | 1,148,000 | 1,038,000 | -12.9 | -13.8 | -22.1 |
| 1937 | 6.6 | 5.5 | 955 | 1,069,300 | 0.41 | 1,280,000 | 1,169,000 | 1,038,000 | +19.8 | + 9.4 | - 2.9 |
| 1938 | 7.0 | 4.1 | 1108 | 1,616,100 | 0.48 | 1,400,000 | 1,292,000 | 1,182,000 | -13.4 | -20.1 | -26.8 |

[a] October of previous year.

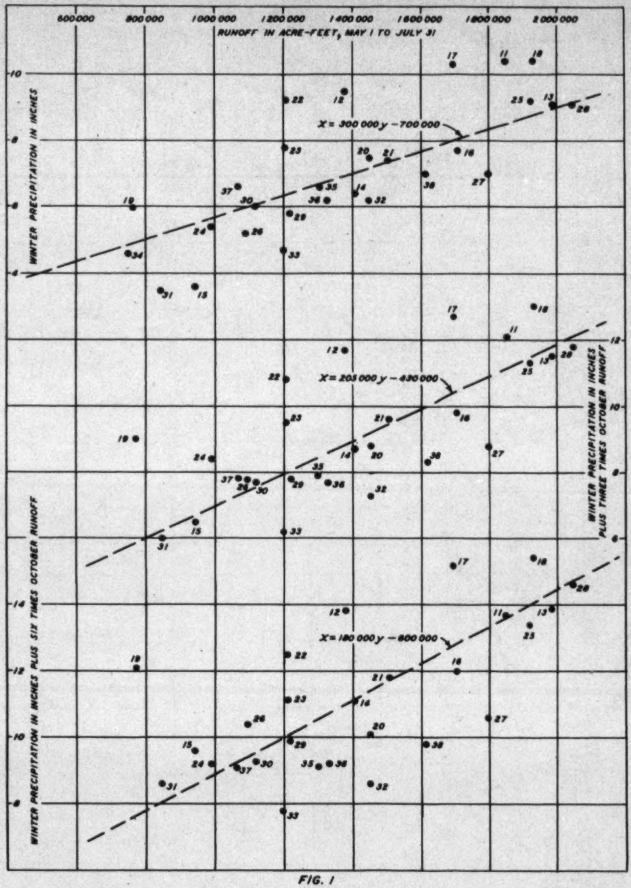

FIG. 1

and the percentage-errors. Precipitation for the period November 1 to April 30 was considered as winter precipitation. The period from May 1 to July 31 was chosen as the period of spring runoff. Values of the above for each year of record were plotted with runoff as abscissas and precipitation as ordinates as shown on Figure 1. A straight line was drawn which seemed to give the best average for the entire period. The equation of this average line is $x = 300{,}000\ y - 700{,}000$, in which x is the runoff in acre-feet during the spring runoff and y is the precipitation in inches for the winter period.

The runoff in acre-feet for May 1 to July 31 of each year was computed from the above formula and is plotted in Figure 2. The trends of the two lines are similar but there are wide variations for individual years.

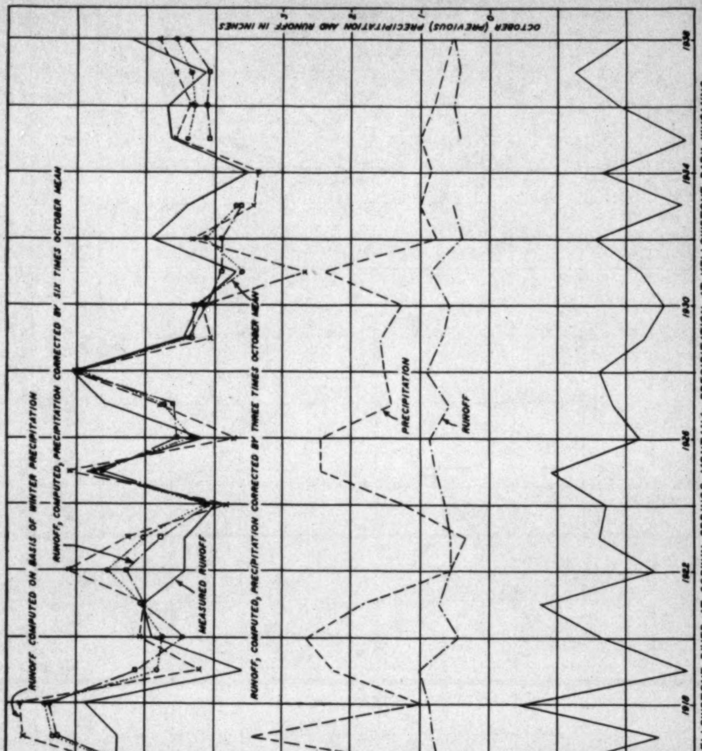

FIG. 2—RUNOFF FOR YELLOWSTONE RIVER AT CORWIN SPRINGS, MONTANA; PRECIPITATION AT YELLOWSTONE PARK, WYOMING

Various methods were tried in attempting to correct for ground-water storage. Minimum flows for October and April were first selected, but the results were unsatisfactory. The minimum flow seemed to be subject to influences, such as abnormal cold spells or other unknown factors, making it a poor index of the ground-water level. The mean flow for October was finally selected and used in the computations.

The mean October runoff for each year was converted into runoff in inches for the 2630 square miles of drainage-area. This value was multiplied by three since the period of spring runoff is three months. Values of the winter precipitation for each year were increased by the above amount and were plotted against the corresponding spring runoff, as before. The equation of the straight line obtained by this method is $x = 205{,}000\ y - 430{,}000$. The spring runoff for each year as computed from this formula is plotted on the Figure. For most years, these points lie closer to those showing the actual runoff than do those computed from precipitation uncorrected for ground-storage.

An inspection of the amount of correction obtained by the above method showed that for most years a larger correction was needed. Therefore, instead of multiplying the October runoff in inches by three, it was multiplied by six. This value was used in correcting the winter precipitation and a third straight line was obtained. The equation of this line is $x = 180{,}000\ y - 600{,}000$. Plotted values of the spring runoff computed from this formula seem to lie a little closer to the actual runoff than do those for either of the previous formulae. For several years this is not true, and in several years none of the computed values are close to the actual.

Spring runoff, as computed by the third method, differed from the actual runoff by more than 20 per cent for the following ten years: 1912, 1917, 1919, 1922, 1927, 1932, 1933, 1935, 1936, and 1938. For the years 1917, 1919, and 1922 the precipitation during the spring runoff-period was abnormally low and may partly explain the large differences between the computed and actual runoff. For the other seven years, there seems to be no distinct reason for these differences.

The percentage-differences between the actual runoff and the computed values were calculated and tabulated in Table 1. Table 2 summarizes Table 1.

Table 2--Comparison of computed runoff with measured runoff

| Difference | Computed from winter precipitation (28 years' total) | Corrected, three times October runoff (27 years' total) | Corrected, six times October runoff (27 years' total) |
|---|---|---|---|
| Less than 20 per cent | 15 years | 18 years | 17 years |
| Less than 10 per cent | 10 years | 15 years | 11 years |
| Less than 5 per cent | 5 years | 9 years | 8 years |

The results as shown above are far from conclusive. However, they do indicate a relationship between the October runoff and that of the following spring. A study of the Figure shows that for years of extremely high or low winter precipitation there is a decided improvement by using the corrected precipitation.

With a more representative precipitation-record, or snow-surveys, and further study as to the best method of correcting for the October runoff, it should be possible to make satisfactory predictions of spring runoff at this station.

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## THE INFLUENCE OF AUTUMN RAINFALL ON THE RUNOFF FROM MELTING SNOW

R. C. Farrow

Up until now only two periods of the precipitation-year have generally been considered in relation to snow-surveys: (1) The accumulative period, broadly speaking, November to March, inclusive; and (2) the runoff-period April to August or September. It has been pointed out by numerous writers that if the soil beneath the snow-mantle is dry the melting snow itself will have to reprime the soil before runoff can occur, and this represents a loss to runoff. In arid regions this loss may obviously represent a large percentage of the snow water-content.

As the autumn rains create the moisture-condition of the soil before the snow begins to accumulate, we have the third period of the precipitation-year, which we might call the soil-priming period.

The writer suggested the study of soil-priming as part of a research project under Dr. Bowie's Project and Planning Committee, and it was endorsed by the Executive Committee as "Farro Project No. 3 [Trans. Amer. Geophys. Union, 1938, p. 577] with constructive comments thereon by J. E. Church and Robert E. Horton. The writer's memorandum to the Project and Planning Committee outlined this portion of the project. His approach to the problem is as follows:

> "In the foregoing, no account was taken of any precipitation during September and October, but from another standpoint this autumn precipitation may exert a considerable influence on the snow-runoff ratio by priming the soil to a lesser or greater degree.
>
> "It is increasingly evident that in many areas the evaluation of the soil-moisture content when melting of the snow-mantle begins is an important factor. If the soil is wet, most of the melting snow should accrue as runoff; if dry, the melting snow itself will have to reprime the soil before runoff can take place. Since the moisture in the soil at the beginning of the snowfall-season is dependent on autumn rains, it may well be that the latter can be used as an index to the former.
>
> "At one extreme there are those areas which even in minimum years receive sufficient autumn rain to completely prime the soil. At the other extreme are the arid regions where snow normally falls on dry ground, and the yearly toll from the snow-cover for repriming will tend to remain a constant.
>
> "Between these extremes there should be many cases where the extent of the autumn rains is relatable to the deficiency between snow water-content and runoff.
>
> "The writer has attempted to develop this theory in the Okanagan Basin. Here the recorded November-March precipitation-data showed no relationship to runoff. The first two years of snow-survey data yielded fairly accurate forecasts, but in the third year there was a large error.
>
> "The autumn rainfall at three precipitation-stations was reduced to per cent of normal for each year, and then the three averaged. These were plotted against the deficiency between runoff and snowfall. A curve was then traced through the plotted points and adjusted by interpolation (see Fig. 2).
>
> "Correcting from the curve each year's November-March precipitation and the three years' water-content obtained from snow-surveys brought snowfall and runoff into reasonable agreement for each year of record. No attempt has yet been made to define the mathematics of this curve.
>
> "Further study of this relationship may be very worth while in areas where the soil-moisture content may vary from year to year.
>
> "The writer, for want of a better name, has called this the "soil-priming factor" and the coefficient obtained from the curve the "soil-priming coefficient."
>
> "This study follows on logically from the previous one and rounds out the precipitation year which has now been divided into three periods: (1) The accumulation-period; (2) the runoff-period (both mentioned before), and (3) the soil-priming period."

Thinking in terms of the "soil-priming period" the expressions "soil-priming factor" and "soil-priming coefficient" were coined by the writer. It is to be hoped that the use of these expressions will be dropped and forgotten. The nomenclature of hydrologic terms is wide enough already. The problem of soil-priming is, in fact, only a part of the problem of surface-runoff and can probably be most scientifically approached through "the infiltration-theory of surface-runoff" as developed by Robert E. Horton and adopted by other authorities. To evaluate the soil-moisture content in the sense under consideration, is to evaluate the "field-moisture deficiency."

Dr. Horton's comment on the project is as follows:

> "May I suggest that the runoff from the snow-cover of a given winter probably depends to a considerable degree on the initial field-moisture deficiency in the preceding fall when snow first begins to accumulate. In regions with deep permeable soils, as in the wheat-growing regions on the Great Plains, this initial field-moisture deficiency may amount to several inches, and a corresponding volume of water derived from melting snow is absorbed by the soil and held till the following growing season without producing runoff. The magnitude of this field-moisture deficiency at a given date can be quite closely approximated from a study of the rainfall of the preceding season in comparison with the normal water-losses by the method which I outlined in a paper presented at the Denver meeting last summer on 'Stabilizing stream-flow.' I would suggest that this method or suitable modification or adaptation thereof be applied in conjunction with Mr. Farrow's research."

In first attempting an approach to this problem, runoff, snowfall, and autumn rainfall were plotted against each other in percentages of normal (see Fig. 1). With very few exceptions, it

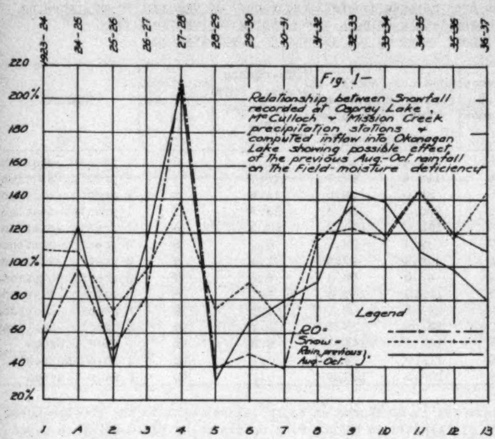
Fig. 1— Relationship between Snowfall recorded at Osprey Lake, McCulloch + Mission Creek precipitation stations + computed inflow into Okanagan Lake showing possible effect of the previous Aug.-Oct. rainfall on the Field-moisture deficiency

will be seen that there is a definite relationship between them.

The correction-curve shown in Figure 2 was then developed, and the past data corrected accordingly. Table 1 shows the result of correcting the data from the curve.

It will be noted how the relationship between snowfall and runoff has been improved by applying the coefficient. Columns (1), (2), and (3) show the original relationship; columns (4), (5), and (6) show the results of correction by applying coefficients taken from the curve. Column (5) is a recapitulation of column (2) for convenience; the numbers in column (7) correspond with the plotted points on Figure 2. The period of record available was at best a short one, and the early records of only one precipitation-station (in any case the weakest of the three) were not above suspicion. The individual data were carefully examined and, in plotting the curve, the greatest weight was given to the data considered most reliable.

It might be thought illogical to plot the curve (Fig. 2) above the ordinate of 100 per cent but it must be remembered that this does not represent the line of field-moisture capacity itself. It is a normal or average based on a short period of record, and might be either greater or less than field-moisture capacity of 100 per cent.

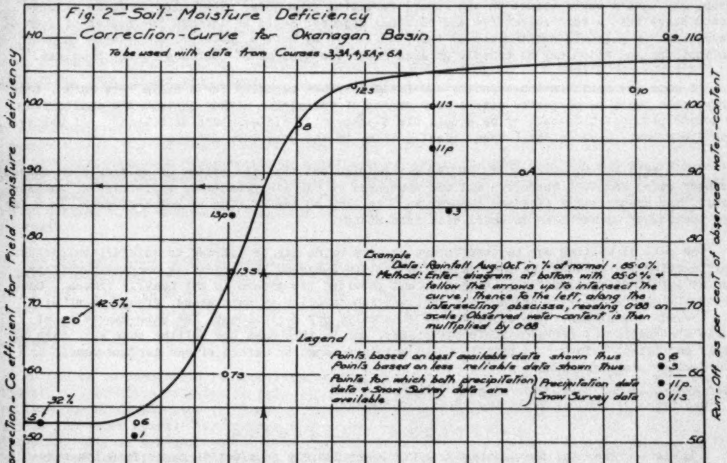
Fig. 2—Soil-Moisture Deficiency Correction-Curve for Okanagan Basin

To be used with data from Courses 3, 3A, 4, 5A, + 6A

Example
Data: Rainfall Aug-Oct in % of normal - 85.0%
Method: Enter diagram at bottom with 85.0% + follow the arrows up to intersect the curve; thence to the left, along the intersecting abscissa, reading 0.88 on scale; Observed water-content is then multiplied by 0.88

Table 1--Disparity for Okanagan Area between snowfall and runoff of Okanagan River, showing results of revising snowfall-data using a curve approximating the field-moisture deficiency based on August-October precipitation

| Year | Snowfall in per cent of normal (1) | Runoff in per cent of normal (2) | Divergence runoff from snow (3) | Snow corrected by curve (4) | Runoff in per cent of normal (5) | Divergence runoff from corrected snow (6) | Point No. in Figure 2 (7) | Remarks (8) |
|---|---|---|---|---|---|---|---|---|
| 1923-24 | 109.0 | 55.5 | 43.5 | 58.4 | 55.5 | 2.9 | 1 | 1 precip.-station |
| 1924-25 | 108.2 | 97.7 | 10.5 | 113.4 | 97.7 | 15.7 | A | 1 precip.-station |
| 1925-26 | 73.0 | 49.5 | 23.5 | 38.0 | 49.5 | 11.5 | 2 | 1 precip.-station |
| 1926-27 | 96.8 | 81.8 | 15.8 | 100.5 | 81.8 | 18.7 | 3 | 1 precip.-station |
| 1927-28 | 138.1 | 211.9 | 73.8 | 155.9 | 211.9 | 56.0 | 4 | 1 precip.-station |
| 1928-29 | 74.4 | 38.7 | 35.7 | 38.7 | 38.7 | 0.0 | 5 | 3 precip.-stations |
| 1929-30 | 90.0 | 47.5 | 42.5 | 48.9 | 47.5 | 1.4 | 6 | 3 precip.-stations |
| 1930-31 | 64.9 | 38.8 | 26.1 | 47.0 | 38.8 | 8.2 | 7 | 3 precip.-stations |
| 1931-32 | 118.8 | 115.8 | 3.0 | 115.9 | 115.8 | 0.1 | 8 | 3 precip.-stations |
| 1932-33 | 123.4 | 136.3 | 12.9 | 131.5 | 136.3 | 4.8 | 9 | 3 precip.-stations |
| 1933-34 | 115.5 | 118.5 | 3.0 | 121.6 | 118.5 | 3.1 | 10 | 3 precip.-stations |
| 1934-35 | 144.4 | 144.4 | 0.0 | 147.2 | 144.4 | 2.8 | 11 | 5 snow-courses |
| 1935-36 | 116.4 | 119.8 | 3.4 | 119.9 | 119.8 | 0.1 | 12 | 5 snow-courses |
| 1936-37 | 144.7 | 109.2 | 35.5 | 109.3 | 109.2 | 0.1 | 13 | 5 snow-courses |

Using precipitation-data in this way is of course an empirical approach to the problem using statistical methods. As the effect of rainfall in maintaining or restoring field-moisture capacity depends to a large degree on the duration and intensity of storms, it follows that the amount of autumn rain from year to year will not produce a proportionate effect on field-moisture deficiency. For instance, intermittent rains spread over a considerable period would produce less effect than the same amount falling in a continuous storm, due to the evaporative processes which would be at work in the intervals between rain-storms. For this reason the graphical method outlined cannot pretend to give more than a close approximation based on average conditions, and its reliability in any particular year will depend on how closely the average is approached.

The results do, however, show that autumn rains and their bearing on field-moisture deficiency may have a major effect on the runoff resulting from snow. They also indicate as mentioned above that a more scientific and rational approach would be through the medium of some of the methods or suitable adaptations of them dealt with by Horton, Bernard, and others in numerous publications and which may be broadly grouped under the heading of "Surface-runoff problems."

If once the infiltration-capacity and field-moisture capacity for a basin were known, snow-survey data could be corrected with a fair degree of certainty, either through the application of autumn precipitation-data or by actual field-tests of field-moisture deficiency. (I believe such field-tests have actually been tried--I think in the Utah Snow-Surveys.)

It is well to remember as Dr. Church has pointed out that the effect of melting snow simulates a steady rain, and that therefore all the processes of surface-detention, infiltration, surface-runoff, and ground-water flow are present and, as long as the melting is uninterrupted, in a far more continuous manner than is usual with rain-storms.

The rate of melting due to temperature or warm rains may be likened to rainfall-intensity. Rapid melting may produce the same effect as "rainfall-excess" by producing surface-runoff as soon as infiltration-capacity is exceeded, and provided the ground is not heavily frozen. Once field-moisture capacity is reached and infiltration-capacity is maintained, ground-water will move towards the stream. The condition of abnormally dry soil beneath the snow-mantle is of course a condition of field-moisture deficiency, and in this case the melting snow will have to supply sufficient moisture to restore field-moisture capacity before either surface-runoff or ground-water flow can occur.

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## ENGINEERS' LUNCHEON

A movie was shown by the Washington Water Power Company on electric power from the snow-fields to the home. Airplane views of the Spokane and Lake Chelan snow-fields and a close-up of snow-surveying were an unexpected demonstration of snow-conditions and snow-survey progress in the Northwest.

# WESTERN INTERSTATE SNOW-SURVEY CONFERENCE

(Chairman H. P. Boardman, Presiding)

## OUTLINE OF SNOW-SURVEYOR'S MANUAL

James C. Marr

[For summary, see present volume, pp. 53-55.]

## CONSTRUCTION OF SNOW-SURVEY SHELTER-CABINS

R. A. Work and R. L. Parshall

This paper is a partial summary of work in part cooperatively conducted by the United States Bureau of Agricultural Engineering, United States Forest Service, Oregon and Colorado Agricultural Experiment stations, and the Works Progress Administration of Oregon. The authors express their appreciation for preparation of the drawings to R. B. Allyn, Jr., Irrigation Engineer, and Gottfried Michaelson.

The success of any snow-survey runoff forecasting program depends in a large measure upon location of the snow-courses and the regularity and accuracy of the actual field-measurements. All other things being equal, snow-courses easily reached are far more desirable than those not so easily reached. As a general rule, however, we believe that accessibility should be subordinated to more fundamental considerations such as freedom from early spring or spotty snow-melting, undue or irregular drifting, character of soil and vegetal cover, etc.

In some watersheds, large portions contributing most of the stream-runoff become isolated to all means of travel except by foot during the snow-season. In these regions the problem of providing permanent adequate shelter-facilities for snow-surveyors must be given careful consideration.

In connection with the expansion of the snow-course network during the past three years, the Bureau of Agricultural Engineering, alone or in cooperation with the Oregon Experiment Station, Works Progress Administration of Oregon, the Colorado Experiment Station, and other agencies, has constructed several snow-survey shelter-cabins. Our experience has been limited and we feel that our methods and designs are subject to considerable improvement. This discussion on the subject of shelter-cabins, therefore, should be considered only as suggestive and based on a relatively brief field-experience.

Of the 11 cabins recently built, only two have been constructed in advance of initiation of the snow-measurements. In the case of the remaining nine shelters, measurements had been taken on nearby courses for periods of one to three years before the shelters were built. Three of these nine shelters were replacements of unsuitable or poorly located shelters and six were constructed to reduce the hazards formerly faced by observers and to increase the regularity of the sampling schedule. Four of these shelters were of the "Oregon deep-snow type" and the others were of various types adapted to territory in which maximum snow-depths do not exceed six to nine feet.

The shelters have, without exception, been located on public land. Where shelters are to be located on National Forest land, it is necessary to first secure a permit for "special use without cost" from the Forest Officer in charge. Issuance of the permit is contingent upon selection of a suitable location, provision of adequate sanitary facilities by the applicant, and shelter-construction of an approved type. The Forest Service regulations are exact, but not exacting.

Points to be considered in locating a shelter-cabin are listed in order of importance, as follows: (1) Location relative to snow-courses or distance to other shelter-facilities (where more than one overnight stop is required to reach a course, we have located our shelters from eight to ten miles apart); (2) freedom from danger of falling trees, or snow- or dirt-slides; (3) availability of suitable timber for logs (the majority of our shelter-cabins have been built with logs, and wood is used for fuel); (4) seclusion (a secluded location so as to be shielded from view of trails or roads is desirable to minimize trespassing); (5) drainage (a well-drained

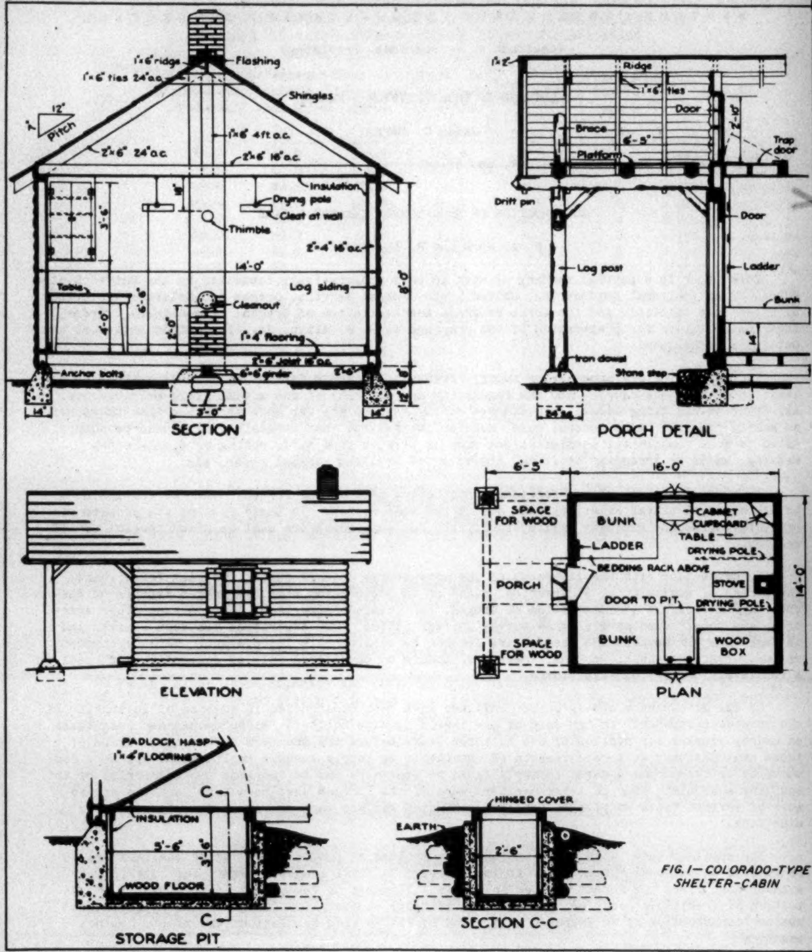
1"×6" ridge
Flashing
1"×6" ties 24" o.c.
Shingles
12"
7"
Pitch
2"×6" 24" o.c.
1"×6" 4 ft. o.c.
2"×6" 16" o.c.
Insulation
Drying pole
Cleat at wall
Thimble
2"×4" 16" o.c.
14'-0"
Table
Log siding
Cleanout
1"×4" flooring
2"×6" joist 16" o.c.
Anchor bolts
6"×6" girder
14"
3'-0"
SECTION
1"×2"
Ridge
1"×6" ties
Door
Brace
6'-5"
Platform
Trap door
Drift pin
Door
Log post
Ladder
Bunk
Iron dowel
Stone step
24"sq.
PORCH DETAIL
ELEVATION
6'-5"
16'-0"
SPACE FOR WOOD
BUNK
CABINET
CUPBOARD
TABLE
LADDER
DRYING POLE
BEDDING RACK ABOVE
PORCH
STOVE
DOOR TO PIT
DRYING POLE
SPACE FOR WOOD
BUNK
WOOD BOX
14'-0"
PLAN
PADLOCK HASP
1"×4" FLOORING
C
INSULATION
5'-6"
WOOD FLOOR
C
STORAGE PIT
HINGED COVER
EARTH
2'-6"
SECTION C-C

FIG. 1—COLORADO-TYPE SHELTER-CABIN

location is desirable); (6) water-supply (the shelters are frequently used during the summer by Forest Service officers or others authorized to do so, and a convenient water-supply is important at this time of year); (7) proximity to pasture is desirable for isolated cabins reached only by pack-train.

In Colorado, where total snow-depth seldom exceeds six feet, a shelter-cabin plan has been adopted which provides a framed structure with log-cabin siding, Celotex-lined, floored, and with the entrance door, which is only slightly above ground-level, protected by an overhanging porch. An emergency gable-entrance is provided as shown in the plan (Fig. 1).

It is important that bedding and supplies stored in such cabins be protected from destruction by rodents. A light-weight rack is suspended by cables of rope or wire at each corner, these cables passing over pulleys hung from the rafters, thus anchoring the mattress, blankets, tarpaulin, and supplies in a hard press against the ceiling. By this arrangement, rats and mice are unable to reach the cache.

The snow-surveyor usually returns from his travels with wet clothing. Suspended from the ceiling, in a horizontal position, are two drying poles on each side of the combination heating and cooking stove. These poles are about six feet long and placed about one foot from the ceiling. This combined length will provide space for four men.

The cache of food in these isolated cabins is of prime importance, since supplies must be protected not only from rodents but from freezing and theft as well. Beneath the floor of the cabin is a concrete pit, bottom and sides lined with Celotex. This insulating board is nailed to pieces one by four inches arranged so as to leave an air-space between the board and walls and floor. A heavy trap-door in the floor, with covered hinges, complete with padlock, covers the pit. After the provisions, in bag containers, are lowered into the pit, a loose metal cover is placed in a recessed section at the top of the concrete walls and on top of this a thickness of Celotex and bags of dry pine-needles are placed to fill the space tight against the under side of the trap-door. In stocking the cabin with supplies of food, it should be kept in mind that something substantial be left in the cabin, within easy reach, in the event of an emergency where a wayworn traveler must have shelter and food.

Other features of this design are built-in bunks, brick chimney resting on the concrete footing or base of the building, heavy storm-shutters over the two 12-light windows, large woodbox filled with firewood, and suitable table, bench, and chairs. The interior is lined with Celotex and the floor is of hard pine. A large sheet of galvanized iron placed on the floor beneath the stove as a protection against fire is an important feature of this design. Bill of materials, exclusive of hardware, paint, stone, logs, poles, and furnishings, is contained in Table 1. Total cost of this type of shelter is estimated at approximately $500.

Table 1--Bill of materials for snow-survey shelter-cabin as per Figure 1 (Drawing No. 3157)

26 sacks of Portland cement, 2.75 cubic yards of sand, and 4.5 cubic yards of gravel for concrete (1:3:5 mix for foundation and piers, and 1:2-1/2:4 mix for storage-pit)
450 common hard-burned brick for chimney
2 sacks of Portland cement, 1 bushel of lime, and 1/4 cubic yard of sand for mortar for chimney
12 linear feet 8" by 8" for terra-cotta flue-lining
6 pieces 2" by 6" by 16' for sills and headers
28 pieces 2" by 6" by 14' for sills and joist headers
32 pieces 2" by 6" by 10' for rafters
1 piece 6" by 6" by 14' for girder
34 pieces 2" by 4" by 16' for plates, sills, studs, and blocking
20 pieces 2" by 4" by 14' for plates, sills, studs, and headers
4 pieces 2" by 2" by 16' for strips for storage-pit
7 pieces 1" by 6" by 16' for ties and corner-brace battens
144 linear feet 1" by 4" for baseboard and roof-ridge
24 linear feet 1" by 8" for ridge
650 feet board measure for roof-sheathing
325 feet board measure 1" by 4" tongue-and-groove fir for flooring
672 square feet Celotex for insulation
750 feet board measure log-cabin siding
2 rolls of water-proof paper (500 square feet per roll)
Shingles to cover 520 square feet of roof
1 five-panel fir door 2'8" by 6'8" with frame and trim
2 windows, double-hung plain rail, 12 lights, 8" by 10" with frame and trim

Note: Hardware, paint, stone, logs, poles, and furnishings are not included.

In Oregon, depth of snow ranges from only a few feet at the lower elevations to such depths in the higher Cascades as to completely bury an ordinary one-story frame structure. Because of this variation in snow-depth, no one type snow-shelter is equally suited for all elevations or locations in Oregon. A type similar in outward appearance to the Colorado-type shelter, but

FIG. 2

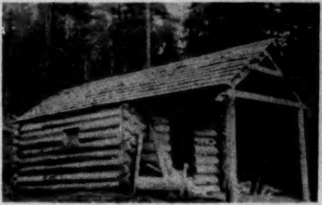

FIG. 3

FIG. 4

FIG. 5

FIG. 7

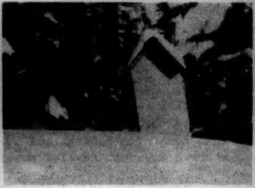

FIG. 8

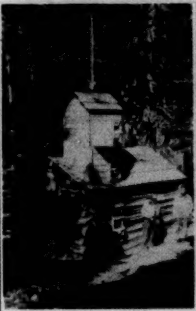

FIG. 11

FIG. 12

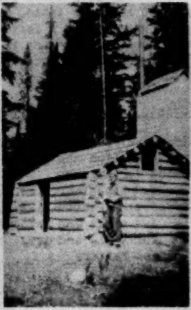

FIG. 13

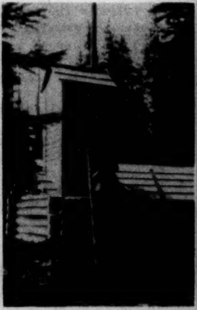

FIG. 14

FIG. 2—CALDWELL RANCH CABIN FIG. 3—ARBUCKLE CORRAL CABIN FIGS. 4,5—WRANGLE GAP CABIN FIGS. 7,8—SEVEN LAKES SNOW-SURVEY SHELTER-CABIN: (7) FALL 1936; (8) APRIL 7, 1937 [NOTE TOWER WRECKED BY UNEQUAL TENSION IN GUY-WIRES] FIGS. 11,12—MOUNT EDDY SNOW-SURVEY SHELTER-CABIN [NOTE IN 12 CHINKING WITH WASTE EDGES OF SHAKE-BOLTS] FIGS. 13,14—WALDO LAKE SNOW-SURVEY SHELTER-CABIN [NOTE IN 14 CEMENT-MORTAR CHINKING AND EXTENSION TOWER-POLE ABOVE RELATIVELY SHORT TOWER FOR FUTURE EXTENSION TOWER IF BECOMES NECESSARY]

constructed of logs, has been developed (Figs. 2 and 3) for use in areas where snow-depth seldom exceeds four or five feet.

A frame-type shelter, adapted to use where maximum snow-depths range up to eight or nine feet, is shown in Figures 4 and 5. Plan-view, elevation, and section-views are shown in Figure 6. Total cost of this shelter-cabin unfurnished was approximately $152.53. This shelter-cabin was constructed by the United States Forest Service, with labor from the Civilian Conservation Corps. Approximately 29 man-days of labor were required.

The third type-shelter used in Oregon, we call the "Oregon deep-snow type." The exact origin of this type of shelter is unknown, but variations of the idea doubtless have been employed in a

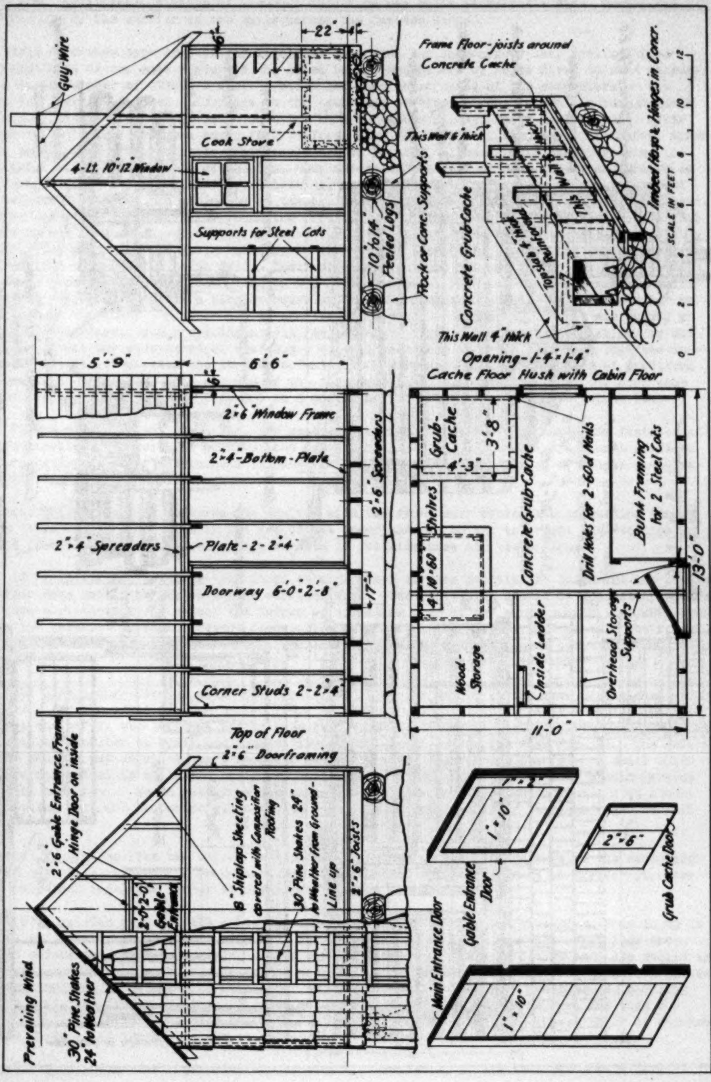
Guy-wire
6"
22"
4"
Cook Stove
4-Lt. 10"×12" Window
Supports for Steel Cots
10" to 14" Peeled Logs
Rock or Conc. Supports
This Wall 6" thick
Frame Floor-joists around Concrete Cache
This Wall 8" thick
Top Slab 4" thick Reinforced
Concrete Grub Cache
Imbed Hasp & Hinges in Concr.
This Wall 4" thick
Opening-1'-4"×1'-4"
Cache Floor Flush with Cabin Floor
SCALE IN FEET
0
2
4
6
8
10
12
5'-9"
6'-6"
6"
2"×6" Window Frame
2"×4" Bottom-Plate
2"×6" Spreaders
2"×4" Spreaders
Plate-2-2"×4"
Doorway 6'-0"×2'-8"
17"
Corner Studs 2-2"×4"
Top of Floor
Grub-Cache
3'-8"
4'-3"
Shelves
4-10-60
Concrete Grub Cache
Drill Holes for 2-60d Nails
Bunk Framing for 2 Steel Cots
13'-0"
Wood-Storage
Inside Ladder
Overhead Storage Supports
11'-0"
2"×6" Doorframing
2"×6" Gable Entrance Frame Hinge Door on inside
8" Shiplap Sheeting covered with Composition Roofing
30" Pine Shakes 24" to Weather from Ground-Line up
2"×6" Joists
2'-0"×2'-0" Gable-Entrance
Prevailing Wind
30" Pine Shakes 24" to Weather
1"×2"
1"×10"
Gable Entrance Door
2"×6"
Grub Cache Door
Main Entrance Door
1"×10"

FIG. 6—FRAME SNOW-SURVEY SHELTER-CABIN

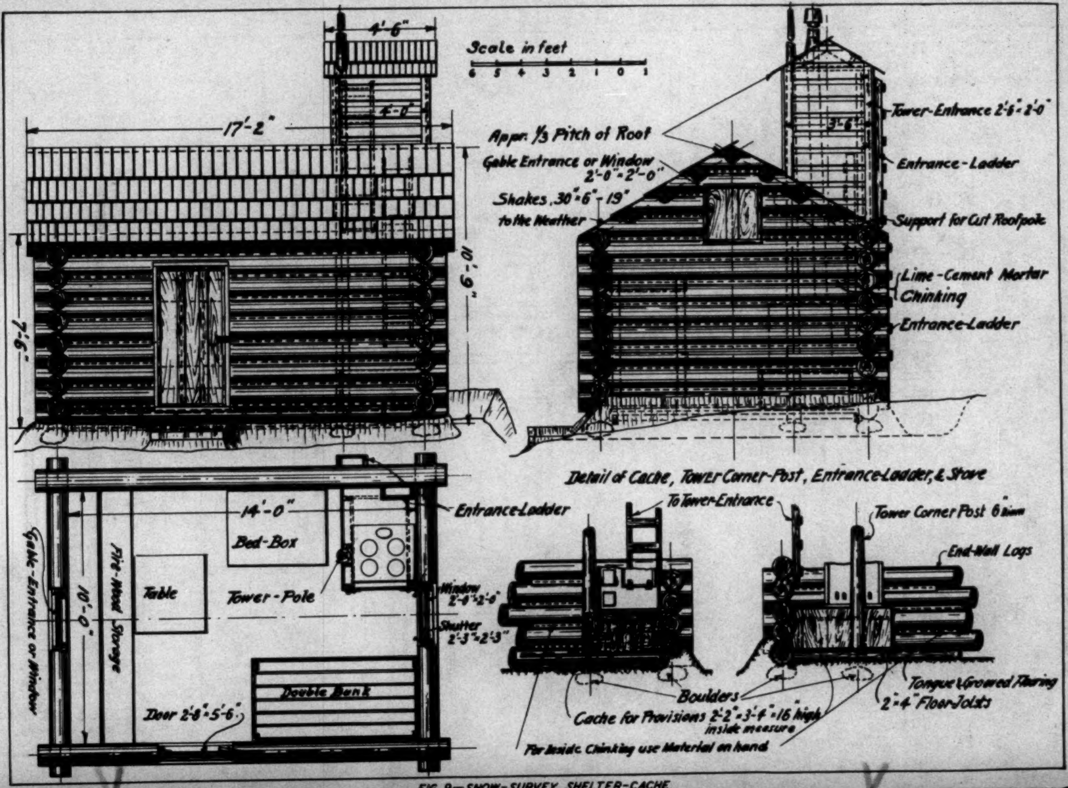
4'-6"
4'-0"
Scale in feet
6 5 4 3 2 1 0 1
17'-2"
10'-9"
7'-6"
Appr. 1/3 Pitch of Roof
Gable Entrance or Window 2'-0"×2'-0"
Shakes, 30"×6"-19" to the Weather
3'-6"
Tower-Entrance 2'-6"×2'-0"
Entrance-Ladder
Support for Cut Roofpole
Lime-Cement Mortar Chinking
Entrance-Ladder
Detail of Cache, Tower Corner-Post, Entrance-Ladder, & Stove
14'-0"
Bed-Box
Entrance-Ladder
Table
Tower-Pole
Window 2'-4"×2'-6"
Shutter 2'-3"×2'-3"
10'-0"
Fire-Wood Storage
Gable-Entrance or Window
Double Bunk
Door 2'-8"×5'-6"
To Tower-Entrance
Tower Corner Post 6" diam
End-Wall Logs
Tongue & Groowed Flooring
2"×4" Floor-Joists
Boulders
Cache for Provisions 2'-2"×3'-4"×16" high inside measure
For Inside Chinking use Material on hand

FIG. 9—SNOW-SURVEY SHELTER-CACHE

great many localities. A cabin of somewhat this type was built in McKenzie Pass, Oregon, in 1877 for use by the carrier of the mails across the Cascade Range.

This deep-snow type shelter, as developed in Oregon for snow-survey use, resulted from the experience of two snow-surveyors who skied to the headwaters of Rogue River to make measurements in the winter of 1936. A shelter-cabin had been constructed at the headwaters of the River the previous October. Entrance to the cabin was provided through a shutter in the gable about eight feet above the ground. When the snow-surveyors reached their goal at dusk, after ploughing their way through a heavy fall of fresh snow for 16 miles, they were, of course, tired, cold, and hungry. Their shelter-cabin could not be located, although both observers knew its location. After considerable discussion, they assembled ten feet of snow-tubing and probed in the snow. During their systematic prospecting, they struck wood at a depth of about ten feet and eventually located the gable end of the cabin. One of the men had wired a shovel in a nearby tree and about 15 feet above ground the previous fall. They luckily discovered about a foot of the handle of this shovel extending above the snow. Alternating then with belt-axe and shovel, they uncovered the gable-entrance to the cabin. A shaft 11 feet in the perpendicular was required to reach the attic door. Their difficulties were not yet completely over, because there was about ten feet of snow piled on top of the iron cover on the stove-pipe. This difficulty was solved by shooting a ring of holes in the cover and then gouging the snow-sampler upward through the cover. By then adding section after section to the sampler, it was pushed up to the snow-surface, thus providing a hole for the stove-pipe. This is the first time, to our knowledge, that any snow-surveyor ever dug a hole 11 feet deep in order to secure inverted snow-samples, but it illustrates the lengths to which snow-surveyors will go in search of practical information. Naturally, this was one of the first shelters to be equipped with the deep-snow entrance-tower (see Fig. 7). Figure 8 is a photograph of the same cabin a few months later.

Figure 9 shows plan, elevation, and section-views outlining the most important features of the construction. Details of construction may not be especially important since most woodsmen or carpenters use their own methods in construction. Perhaps the following principal features warrant consideration here:

(1) Orientation--By locating the shelter with the front door facing the prevailing wind, tower entrance-doors are then in the lee of the tower and not so apt to permit snow to blow in around cracks about the door which are exposed to drifting snow all winter long.

(2) Clearing and leveling--All snags or ripe trees in such position as to damage the shelter if blown down should be felled before starting work. The cabin-site should be adequately cleared for such a distance as to reduce the danger of spreading fire to the woods should the cabin burn, or in the reverse, so as to prevent destruction of the shelter by any ground-fire in the forest. The site should be leveled and ditched in order to drain the surface-runoff completely away from the shelter.

(3) Dimensions--Dimensions of the shelter may vary, depending on the size of the snow-survey parties. For the usual two-man party, 10 by 14 feet is adequate; 12 by 14 feet is adequate for a three-man party; and 12 by 16 feet should be adequate and comfortable for a four-man party. The smallest shelter we built had inside dimensions of 10.5 by 12 feet (see Fig. 7). The size of the shelter may depend in part upon the ease with which logs can be secured. A small cabin is more economical to build and easier to heat than a large cabin. The shelter should provide adequate headroom. Seven feet from the eaves to the floor should be sufficient. With a one-third pitch roof and an inside width of ten feet, the height from floor to ridge would be 10.5 feet.

(4) Foundation--The two bottom logs should be bedded at the four corners of the cabin and at the door-sill on adequate rock-footings. The foundation logs should be of greater diameter than the other logs, the better to delay rotting.

(5) Logs--The logs for the walls are usually selected of pine, if available, from 12 to 14 inches in diameter at the butt. The logs for gable may be of small diameter. All logs are peeled before the courses are laid. It is desirable that the trees be felled and logs peeled in the early summmer while the sap is up and then allowed to season for a month or longer in advance of construction, if this can be arranged. Several types of notching or notching and saddling may be used. We prefer the type of notch and saddle illustrated in Figure 10. The logs for sides and ends fit fairly snugly together, but since the entire building should later be chinked, cracks up to 1-1/2 inches are not to be especially avoided.

(6) Roof-poles--The roof-poles are of pine, if available, of six to eight inches butt-

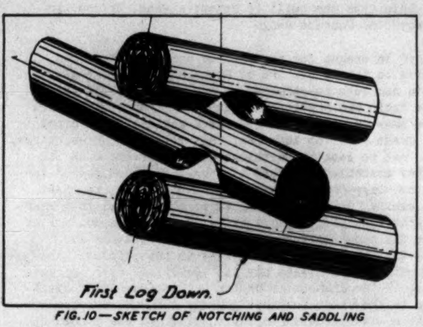

FIG. 10—SKETCH OF NOTCHING AND SADDLING

diameter. The roof-poles run longitudinally of the cabin and lie in notches cut in the gable end logs. Pole-spacing is 18 inches center to center. Poles of this size and spacing will bear a heavy load. The snow-load on the roof of the Seven Lakes shelter-cabin (Fig. 7) was computed from density- and depth-measurements to be 12.5 tons on March 31, 1936. None of the roof-poles were bowed.

(7) Roof--The roof is of split shakes, sawed shakes, or shingles, depending on availability of material. If a long pack-trip with finished lumber is required, it probably will be more economical to split the shakes from material at hand. We have generally used 30-inch split shakes laid shake-fashion 16 to 18 inches to the weather. The first course is laid from the top side log to the first rafter and should have enough overhang to prevent drip down on the side logs, but not so much overhang that weight of snow on the roof will break the shakes off at the log. A four-inch overhang is about right. If finished lumber is hard to get, the shakes may be combed at the ridge leaving a four-inch comb extending up from the windward side. Galvanized roof-nails are preferable for nailing the shakes, but seven-penny box-nails are satisfactory.

(8) Tower--The height of the tower depends upon the depth of snow to be expected. The top of the tower on the cabin shown in Figure 7 is 25 feet above ground-level. The top of the tower on the cabin shown in Figures 11 and 12 is 16 feet above ground-level.

The outside dimensions of the tower are four feet lengthwise of the cabin by 3.5 feet crosswise. The inside vertical corner-pole of the tower is made up from a single straight log timber six to ten inches in diameter at the butt and 20 to 25 feet long. This pole is erected vertically inside the shelter-cabin and foundationed on a concrete block or rock, well settled on undisturbed soil. It is tied into the floor by a system of headers and onto the rafters and the back side and right end walls of the cabin by a system of tie-braces. The remaining three outside corners of the tower are of material four by four inches or of small logs erected vertically from top side logs and gable end logs, cross-braced both to each other and to the fourth and inside corner tower-pole. However, no bracing diagonally across the tower is used. The sides of the tower are of one-inch by six-inch drop siding or shiplap.

One or more doors two feet by two and one-half feet are cut in the lee side of the tower. Usually only one door near the top of the tower will need to be provided (see Fig. 11). If the tower is exceptionally tall, two entry-doors should be provided, one at the top and the other about ten feet above ground.

For a short tower, the inside corner-pole plus cross-bracing will provide such strength that the tower need not be guyed to prevent its being blown off the cabin. Very tall towers will probably need to be guyed to the cabin-corners or nearby trees. Guys of unequal length should be avoided because unequal ice- or snow-loads on the guy-wires may twist the tower out of shape (see Fig. 8). Ladders both inside and outside the tower are needed to provide entry to the cabin through tower-doors.

The stove-pipe should run right up the inside of the tower, with two or more baling-wire cross-braces to make it rigid. It is essential that a damper be provided in the pipe because the great length of stove-pipe required to reach the tower-top creates considerable draft in an ordinary small kitchen-range. Any sort of a cover can be provided for the stove-pipe. We suggest a large tin can or galvanized-iron cup attached to a pole that can be reached from the tower-door. The cover can then be easily removed or replaced when entering or leaving the cabin. It is, of course, necessary to flash around the base of the tower to prevent leakage into the cabin.

(9) Windows, doors, and shutters--Four-light windows about two feet square are provided seven feet above ground in each end of the cabin. The windows are set against outside stops in frames two by six inches and permanently fixed by four strips nailed inside to the framing and

against the sash. Double-thickness solid shutters are set inside the windows against the inside window-stops and held in place by iron pins. The shutters may be readily removed by pulling the pins.

The double-thickness summer entrance-door is 30 inches wide by 66 inches high and three inches thick hung by four 6-inch strap-hinges to open in. Removable pins set through the door framing into the logs on the inside of the door at the lock side prevent the door from being forced inward. This door, of course, is of no use in the winter, but may be opened from the inside if necessary.

(10) Floor--Any rough flooring is preferable to a dirt-floor, but the latter has certainly been a popular type in many shelter-cabins. We have built one or two cabins with dirt-floors but later put in flooring because the cost is very small and the resulting comfort seems worth the small additional cost. We use joists two by six inches on 16-inch centers laid on sleepers two by four inches or two by six inches running longitudinally of the cabin and nailed to the bottom log. Tongue-and-groove flooring one by six inches or ordinary boards one by six inches or one by eight inches may be used. If any effort is made to make the cabin rat-proof, a sound grade of tongue-and-groove flooring should perhaps be used. We have been unable to build a cabin so as to be mouse-proof, but so far have had fair success in keeping the rats out.

(11) Chinking--The cabins shown in Figures 7 and 11 were chinked with moss and battened inside and out with the waste wedges from shake bolts. The cabin shown in Figure 13 was chinked with lime cement-sand mortar. This type of chinking is rapid and more satisfactory than chinking with moss or similar material. In applying the cement-mortar chinking, small willow-poles were first nailed in the cracks between logs on the inside of the cabin. Eight-penny common nails were then driven into the logs on the outside at six-inch intervals alongside the longitudinal crack between logs. These nails keep the chinking from falling out when it dries.

(12) Locks--As a general rule, we have not encouraged the use of snow-survey shelter-cabins by the public. The shelters, accordingly, are all protected by locks keyed alike.

(13) Trespass-signs--For the present we are using the standard United States Forest Service four-inch by six-inch penalty signs.

(14) Interior arrangement--An economy of arrangement of housekeeping facilities is dictated by the relatively small floor-space of the ordinary shelter-cabin. The entire inside left end of the cabin is devoted to wood-storage. A supply of wood sufficient for three or four winters ordinary use can be stored against the left end wall of the cabin. A bed-box of two-inch by six-inch tongue-and-groove material four feet long, three feet wide, and two and one-half or three feet high is built against the back wall of the cabin on the floor-joists, thus saving on flooring. Lanterns, mattresses, bedding, cooking utensils, and miscellaneous articles are stored in this locked box between visits to the shelter.

The bunks are three feet by six and one-half feet of tandem style, the lower 20 inches above the floor and the upper 56 inches above the floor. The disadvantage of this type of bunk lies in the fact that the fellow upstairs becomes too warm when the fellow downstairs chunks the stove in order to thaw out those frosted toes. However, the saving in space over a double-width single bunk is worth considering. In one shelter we use collapsible canvas-cots instead of the tandem bunks. Usually the bunk has a few one-inch by six-inch boards for springs, but in one shelter we built single-width iron spring-cots into the bunk framing.

The matter of preservation of food from theft and from freezing is sometimes perplexing. We have so far tried cellars and various types of caches, insulations, etc. Our cellars even when made of concrete have become flooded. So in Oregon, at present, we are building a reinforced-concrete box in the back left-hand corner of the cabin, having inside dimensions of length, width, and height of 40 to 48 inches, 26 inches, and 16 to 18 inches, respectively. The walls, top, and bottom are from 6 to 18 inches thick. The door is hinged on heavy hinges set in the concrete floor and the heavy safety-hasp is likewise set in the concrete top. The door is of triple thickness or of concrete. So far, we have had no trouble with food--other than potatoes--freezing in the cache. Some snow-surveyors, however, have complained about undue molding of supplies in this cache. These complaints, in every case, have originated the first winter after the cabin was built. Since our cabins mostly were built from September to November, and stocked immediately on completion, it seems likely that molding may have been due to high humidity in the boxes, caused by the slowly curing concrete. This heavy molding, of course, occurs in a newly constructed concrete pit. After the first season, there is no more molding in a concrete box than in a pit.

The stove sits on top of the concrete food-box. It may be necessary to sheet the wall of the cabin with asbestos paper to prevent bad charring from the heat of the stove. This will depend largely on the size and shape of the stove. There are two possible objections to this location for the stove: First, since the stove fire-box is from 24 to 36 inches above the floor, it takes a long time to heat the air near the cabin-floor; second, since the stove sits directly under the tower-entrance, much heat is lost up the tower-entrance because of its chimney-effect.

If the cabin were built in a well-drained location, where there was no chance of a cellar being flooded, it would be better to substitute a cellar cache for the floor-level cache, thus allowing the stove on the floor. The stove might then be placed along the rear wall of the cabin, not directly under the tower. The stove-pipe, of course, should still be brought up through the tower.

(15) Painting--All windows, shutters, doors, frames, etc., should be painted. In fact, all the finished lumber in or on the shelter should be given two coats of lead-and-oil paint. This not only adds materially to the life of the wood, which is subject to the severest sort of exposure, but somewhat improves the appearance of the shelter.

Costs of these shelters vary somewhat, depending on the difficulties encountered in securing proper materials, distance from points accessible to automobile, etc.

The total cost of the Seven Lakes shelter-cabin (see Fig. 7) including all labor, pack-train hire, supplies for subsistence, complete cabin-furnishings, emergency rations for winter, and six weeks' wood-supply left in the cabin, and crew-travel to and from end of motor transportation was $439. Total cost of the Mount Eddy shelter, covering the same items, was $340. The Eddy shelter cost $100 less than the Seven Lakes shelter, largely due to difference in pack-train cost and to the further fact that suitable logs were more readily secured in case of the Mount Eddy shelter.

Total cost of the Waldo Lake shelter was $350. This total cost, unlike the costs of the other shelters, does not include cached emergency winter food-supplies and does not include any furnishings for cabin beside the stove. Addition of these latter items would increase the total cost to about $410 as compared with similar totals of $439 and $340 for the other two shelters mentioned.

From 50 to 58 man-days were required to completely construct one of these deep-snow shelter-type cabins. Crews ranged in number of men from four at Seven Lakes to ten at Waldo Lake.

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## DISCUSSION

J. E. CHURCH--Entrance-towers are the inevitable response to man's search for shelter. In the Sierras, these towers are called "Santa-Claus chimneys." The first cabin of this type for snow-surveyors was constructed in the early 1920's at 9000 feet on the headwaters of the East Walker River near the northern boundary of Yosemite National Park.

Where possible, wind-blown spots should be selected as sites for shelter-cabins to assure the greatest shallowness of snow. No delay should be incurred by the weary and sometimes sweating surveyor in obtaining warmth and relaxation. At such times any shoveling is toilsome.

The use of cables to steady the tower can readily result in failure despite the even length of the cable-spans, for under the stress of heavy snow or particularly ice-festoons one of the cables may yield and thus increase the leverage of the other cables. On Mount Rose the eyes of even 3/16-inch iron guy-rods have been pulled open, thus increasing the potential strain of the other guy-rods until even the T-couplings of the meteorograph-masts were broken and the masts were dragged down. The only reliable support for entrance-towers are braces (not cables) of sufficient strength to carry any load of snow or ice without crumpling.

Judging from the size of the rafters and the thinness of the shakes of the shelter-cabin at Seven Lakes, it seems improbable that the roof actually bore the total weight of 12.5 tons represented by the snow-cover above it. More probably, the snow-mass became sufficiently coherent before the upper strata were accumulated to carry the additional load. Such would be the case if a culvert were being covered by accumulating cement. The first pouring would support the later ones with little additional burden on the culvert beneath. Here is an interesting problem.

This, of course, does not apply to a roof projecting above the snow. Here wreckage is caused by the transference of melt-water to the eaves where it accumulates as ice in sufficient quantity to break them down or distort the building through uneven strains.

The rat-nuisance can be abated only by building the cabins of metal. Rats can readily climb rough walls and gnaw through. They will leap if the inducement is sufficiently great. Even the floors must be underlaid with sheet metal or fine-meshed screen. Poisoned grain was merely gathered up by the rats and stored in one of our felt-boots as an exhibit.

Little immunity can be created for beds and leather by hanging them from the ceiling, particularly when the distance from walls or ceiling is small. A tin-lined bed-box will give full protection.

A fairly satisfactory substitute for metal containers are heavy bags of canvas. Canvas seems to be unpleasant to the teeth of the rat. Only twice was canvas cut through--once when a rat was imprisoned in a tiny sand-bag hut by snow-drift and ate his way out through the canvas-door; another time when the smell of oats cached in the bedding proved too alluring. The bedding alone never attracted the rats to gnaw through canvas. However, probably only tin will furnish protection for the leather straps and rawhide thongs of ski and snow-shoes. The rats, like arctic dogs, are wild for rawhide and eat it with audible relish.

Locks should be set beneath or behind a plate sufficiently impenetrable to stop bullets. Padlocks are opened by the simple expedient of shooting them up--whether by revolver or a high-powered rifle is uncertain. This menace is greater near the towns where pilfering is considered a sport.

## IMPROVEMENT OF APPARATUS

### SHIELDED STORAGE PRECIPITATION-GAGES

Ashton R. Codd

[For details, see this volume, pp. 77-79.]

### ACCURACY OF MOUNT ROSE SPRING BALANCE

Leupold, Volpel, and Company

A comparison of the relative accuracy of the Mount Rose spring balance as improved by them and the Mount Rose balance (Chatillon type) with iso-elastic springs was attempted, but the graduations of the two instruments were based on slightly different standards. Therefore, only the graph of the former (Fig. 1) is presented.

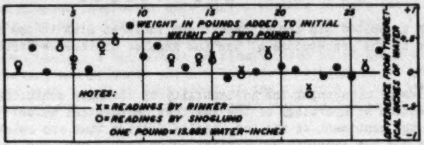

FIG. 1—TEST OF MOUNT ROSE SCALE

### DISCUSSION

Mr. STEVENS comments as follows:

"The zero-line of Figure 1 represents the standard and the points show the errors of the readings. An initial weight of two pounds was for a container for which the scale was carefully adjusted to zero. Successive loads of one, two, three, etc., pounds were placed in the container and the scales were read. Two observers, Mr. Rinker and Mr. Shoglund, made independent readings for each load in order to reduce observational errors. Brass weights, recently certified, were used. The difference between the readings by Rinker and Shoglund is due in part to parallax and the difference in estimating the decimal between two marks.

"The Leupold, Volpel, and Company scale is well within the observational error of ordinary field-work. The graduations on the Leupold, Volpel, and Company dial may not be quite uniform and are not so accurate as one that would be made today on a new engraving machine recently installed. We did not check the graduations. I am sure they can make a weighing scale and dial now that will follow any standard adopted much closer than that on the accompanying Figure 1."

As noted above, Mr. STEVENS believes that the accuracy of the simple springs can be still further improved. The problem of obtaining iso-elastic springs of smaller size but with their present tensile strength deserves attention.

In a later letter to Dr. Church, Mr. STEVENS states:

"The standard used for comparing the Mount Rose and the Chatillon scales was based on 1.5-inch diameter cutter and a specific weight of water of 62.5. I enclose a standard of comparison based on a cutter diameter of 1.5 inch and a specific weight of 62.4 which I believe is the true standard with which the Mount Rose cutter and scale should be compared.

"We could make another scale to this standard and, I believe, could bring it in very close agreement throughout the entire range indicated."

Table 1--Standard for Mount Rose snow-sampler

| Weight added to initial weight of 2 pounds | Precipitation 1.500-inch cutter specific weight 62.4 pounds | Weight added to initial weight of 2 pounds | Precipitation 1.500-inch cutter specific weight 62.4 pounds |
|---|---|---|---|
| lbs | inches | lbs | inches |
| 1 | 15.67 | 16 | 250.73 |
| 2 | 31.34 | 17 | 266.40 |
| 3 | 47.01 | 18 | 282.07 |
| 4 | 62.68 | 19 | 297.74 |
| 5 | 78.35 | 20 | 313.42 |
| 6 | 94.02 | 21 | 329.09 |
| 7 | 109.70 | 22 | 344.76 |
| 8 | 125.37 | 23 | 360.43 |
| 9 | 141.04 | 24 | 376.10 |
| 10 | 156.71 | 25 | 391.77 |
| 11 | 172.38 | 26 | 407.44 |
| 12 | 188.05 | 27 | 423.11 |
| 13 | 203.72 | 28 | 438.78 |
| 14 | 219.39 | 29 | 454.45 |
| 15 | 235.06 | 30 | 470.12 |

## REPORTS AND IDEALS

Chairman BOARDMAN presented his annual report and included with it the financial report. Both are printed above in the proceedings of the Los Angeles Conference [Transactions for 1939, pp. 94-95].

A discussion followed, concerning the advisability of formally consolidating the Snow-Survey Conference with the Section of Hydrology of the American Geophysical Union. Chairman Boardman explained that it was the sentiment of the Los Angeles meeting that the relations between the Snow-Survey Conference and the American Geophysical Union should continue in an informal way. A motion to endorse the resolution of the Los Angeles meeting for the current year carried.

A second motion to increase the number of members of the Executive Committee also carried.

O. W. MONSON was elected to membership on the Executive Committee of the Western Interstate Snow-Survey Conference.

The Northwest Scientific Association formally offered the Section of Hydrology and Snow-Survey Conference the privileges of its organization whenever it seemed feasible to meet with it and also provided free publication of a general report in "Northwest Science."

Tribute was paid by J. E. CHURCH to W. A. LAMB, Chairman of the Regional Committee and member of the Executive Committee of the Snow-Survey Conference. Still young in years but old in service, Lamb had been a comrade and leader in problems of water and snow, and demonstrated that the forecasting and distribution of international streams need have no trace of misunderstanding or selfishness.

Dr. CHURCH looked forward to the leadership of Mr. Monson who had been persuaded to take up Mr. Lamb's duties as Chairman of the Regional Committee and was now being elected to fill his place on the Executive Committee.

C. E. DRYSDALE, who had been present throughout the meeting as a representative of the National Park Service, expressed deep interest and desire to cooperate.

R. C. FARROW could not attend as he was snowbound while attempting to reach Spokane for the meeting. He sent a telegram and later a letter of regret.

Letters were later received also from W. E. Maughan and C. S. Heidel, members of the Regional Committees, and are quoted in part below:

W. E. MAUGHAN--"It would be impossible for one in my position not to recognize and appreciate the greatly increased public and professional interest in problems relating to meteorology and hydrology of the North Continental Divide Area. Material evidence of this interest has appeared almost daily in the form of an ever-increasing number of requests to the Climatological Section Center at Helena for data of a hydrologic nature.

"It is realized of course that much of this increased interest is the aftermath of recent flood and devastating drought-conditions, as well as in connection with the construction and purposes of the great storage-projects for the Columbia and Missouri River drainage-systems. The character and scope of interest, however, has broadened in recent years and, in my opinion, reflects the prominence directed to these problems by the more practical and successful methods of investigation now being adopted or attempted by the various agencies and organizations concerned with their solution. The importance of these problems has always existed. That they now assume a greater measure of importance may be largely ascribed to the greater and more immediate need for the information and the publicity given them.

"Most important problems for hydrologic research have been enumerated by Dr. Church and others in recent publications of the American Geophysical Union and elsewhere. Successful pursuit of such research will depend to great extent upon the assistance from State, Federal, and private sources, and in the form of adequate equipment, funds, and other help. It is therefore encouraging, I believe, to note this increased interest which eventually will favorably influence more assistance from the sources mentioned."

C. S. HEIDEL--"The snow-surveys with which I have had most experience are those in the Swift Current Basin, the results of which are relied upon to a considerable extent in the operation of the Milk River Project.

"These surveys, as you know, are used primarily to aid in regulation of Sherburne Storage, only a few miles away, even though the water is used and supplemental storage developed several hundred miles to the east.

"Application of Missouri headwater snow-survey results to Fort Peck regulation is an interesting variation from the Swift Current-St. Mary-Milk River problem.

"Since last year was my first one handling details of international water-division in the St. Mary and Frenchman basins, I had almost no time to even think about other matters except the routine eastern tributary measurements which I have been working on for years. But now I am more familiar with it, and even though we have about 15 new stations in the Battle Creek Frenchman Area in southern Saskatchewan, I guarantee to answer every letter which comes from you."

## LIST OF PERSONS ATTENDING MEETING

H. P. Boardman, Professor of Civil Engineering, University of Nevada, Reno, Nevada
J. P. Bonner, Soil Conservation Service, Moscow, Idaho
John F. Breakey, Bureau of Ent. Blister Rust Control, Spokane, Washington
Lloyd A. Burnett, Soil Conservation Service, Moscow, Idaho
A. B. Butler, High School Science, Pasco, Washington

J. E. Church, University of Nevada, Reno, Nevada
Ashton R. Codd, U. S. Weather Bureau, Salt Lake City, Utah
E. H. Collins, Washington Water Power Company, Spokane, Washington
L. J. Cummings, Northern Rocky Mountain Forest and Range Experiment Station, Missoula, Montana
H. J. Doolittle, District Highway Engineer, U. S. Indian Service, Spokane, Washington
C. E. Drysdale, Associate Engineer, U. S. National Park Service, 307 Lowman Building, Seattle, Washington
John H. Fisken, Washington Water Power Company, Spokane, Washington
D. B. Freeman, Corps of Engineers, War Department, Kansas City, Missouri
H. T. Gisborne, Northern Rocky Mountain Forest and Range Experiment Station, Missoula, Montana
Thomas B. Hayward, U. S. Weather Bureau, Spokane, Washington
W. A. Hill, Washington Water Power Company, Spokane, Washington
U. B. Hough, Consulting Engineer, Spokane, Washington
L. T. Jessup, Bureau of Agricultural Engineering, Box 324, Yakima, Washington
Edward C. Johnson, State College of Washington, Pullman, Washington
Walter E. Johnson, Washington Water Power Company, Spokane, Washington
Mark R. Kulp, Agricultural Experiment Station, University of Idaho, Moscow, Idaho
James C. Marr, Bureau of Agricultural Engineering, Boise, Idaho
G. R. McDole, Soil Conservation Service, Spokane, Washington
P. C. McGrew, Soil Conservation Service, Spokane, Washington
C. R. Meils, Washington Water Power Company, Spokane, Washington
O. W. Monson, Montana Agricultural Experiment Station, Bozeman, Montana
H. H. Rhodes, Geographer, Pullman, Washington
C. S. Schopmeyer, Northern Rocky Mountain Forest and Range Experiment Station, Missoula, Montana
Sam L. Sloan, Soil Conservation Service, Spokane, Washington
C. Svendby, Soil Conservation Service, Spokane, Washington
H. M. Wanser, Soil Conservation Service, Spokane, Washington
L. L. White, U. S. Forest Service, Sandpoint, Idaho
R. A. Work, Engineer, Bureau of Agricultural Engineering, Medford, Oregon

## ACKNOWLEDGMENT

The Section of Hydrology and Snow-Survey Conference are under deep obligations to the Northwest Scientific Association and the Davenport Hotel for their generous hospitality and to Chairman Monson for preparing a full report of the joint meeting for "Northwest Science."

The Nevada Agricultural Experiment Station has continued its generous clerical assistance in connection with the vice-presidency of the Section of Hydrology and the editing of the proceedings of the Snow-Survey Conference.

Because of the early printing of the Transactions, it has been impossible to receive answers from all of the organizations that have thus far assisted in procuring and distributing reprints. However, the answers received indicate additional contributors and continued support for the work. The list of contributors must of necessity be reserved for the Transactions for 1940.

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